APTD-0908

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CONTAMINANT EMISSIONS IN THE LOS ANGELES BASIN--THEIR SOURCES, RATES, AND DISTRIBUTION

Appendix A

of

Development of a Simulation Model
for Estimating Ground Level Concentrations
of Photochemical Pollutants

Prepared by

Systems Applications, Inc.
Beverly Hills, California 90212

for the

Air Pollution Control Office
of the Environmental Protection Agency
Durham, North Carolina 27701

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16. Abstracts
The emissions inventories developed for the major moving and fixed sources of pollution in the Los Angeles Basin are presented in detail. Particular emphasis was placed on developing a detailed representation of the spatial and temporal traffic distribution in the Basin, as vehicular emissions account for approximately 97% of CO, 85% of reactive hydrocarbon, and 62% of NO_x emissions. Attention was also given to those sources which, while responsible for only a small proportion of emissions on an area-wide basis, contribute heavily to pollutant concentration levels in their own locale--airports, power plants, and refineries. Average daily emissions rates of NO_x, organic gases and CO into the atmosphere of the Los Angeles Basin are tabulated.

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CONTENTS

	Page
INTRODUCTION	A-1
I. AUTOMOTIVE EMISSIONS	A-1
A. Automobile Emissions Model	A-4
1. Exhaust emissions	A-5
2. Crankcase emissions	A-7
3. Evaporative losses	A-8
B. Summary of Major Assumptions and Presentation of Results	A-8
C. The Calculations and Data Sources	A-15
1. Spatial distribution of traffic	A-15
2. Temporal distribution of traffic	A-17
3. Pollutant emissions rates	A-19
References	A-32
II. AIRCRAFT EMISSIONS	A-33
A. Aircraft Emissions Model	A-33
B. Emissions and Airport Data	A-38
References	A-47
III. FIXED SOURCE EMISSIONS--POWER PLANTS AND REFINERIES	A-47
A. Power Plant Model	A-47
1. Treatment of point source emissions as volume sources	A-49
2. Emissions and other relevant data	A-49
B. Oil Refinery Model	A-59
1. Distribution of emissions	A-59
2. Emissions and other relevant data	A-59
C. Alternate Models for Large Point Sources	A-65
1. Estimation of local concentrations for steady state, non-reacting plumes	A-65
2. Further suggestions for the treatment of large point sources	A-69
References	A-70

		Page
IV.	FIXED SOURCE EMISSIONS--DISTRIBUTED SOURCES	A-71
	A. Oxides of Nitrogen	A-71
	B. Organic Gases	A-76
	C. Carbon Monoxide	A-77
V.	CONTAMINANT EMISSIONS INVENTORY OF THE LOS ANGELES BASIN . .	A-80

INTRODUCTION

Perhaps the most tedious and mundane aspect in the development and validation of a simulation model of reaction and dispersion processes in the atmosphere is the compilation of a complete contaminant emissions inventory. Yet, such an inventory is a *sine qua non* in model validation and, if done properly, the emissions estimates probably constitute the most precise segment of requisite input data. Contrast, for example, the relatively low magnitudes of errors in emissions estimates with the imprecision of wind speed and direction estimates, both at the surface and aloft, as well as with the uncertainties in estimates of the variation in mixing depth with location and time. Furthermore, an emissions inventory need be carried out but once to serve as an adequate representation of a region, whereas meteorological data must be collected for each validation day, and for the purposes of this modeling venture, represented through hourly variation in wind field and mixing depth. It thus seemed wise to put a considerable effort into the establishment of an accurate emissions inventory for the Los Angeles Basin.

Particular emphasis was placed on developing a detailed representation of the spatial and temporal traffic distribution in the Basin, as vehicular emissions account for approximately 97% of CO, 85% of reactive hydrocarbon, and 62% of NO_x emissions. Attention was also given to those sources which, while responsible for only a small proportion of emissions on an area-wide basis, contribute heavily to pollutant concentration levels in their own locale--airports, power plants, and refineries. (We have indicated in Figure A-1 the locations of these major sources, as well as the locations of all freeways and monitoring stations.) In this Appendix, we present in detail the emissions inventories developed for the major moving and fixed sources of pollution in the Los Angeles Basin.

I. AUTOMOTIVE EMISSIONS

The magnitude of contaminant emissions from a motor vehicle is a variable in time and is a function of the percentage of time the vehicle is operated in each driving mode (accelerate, cruise, decelerate, idle). The modal split is in turn dependent on the habits of the driver, the type of street on which the vehicle is operated, and the degree of congestion on that street. Also affecting emissions are the presence or absence of a smog control device, the condition of the car, its size, and other factors. The distribution of vehicles in time and location throughout an urban area is similarly governed by a number of factors--commuting routes, distribution of centers of employment, shopping centers, residential and recreational areas, topography, the occurrence of special events, etc. Thus, precise calculation of the magnitude of emissions as a function of location and time is clearly not possible.

A number of studies have been conducted in recent years having as their objective the development of a vehicle emissions inventory for

Figure A-1 follows

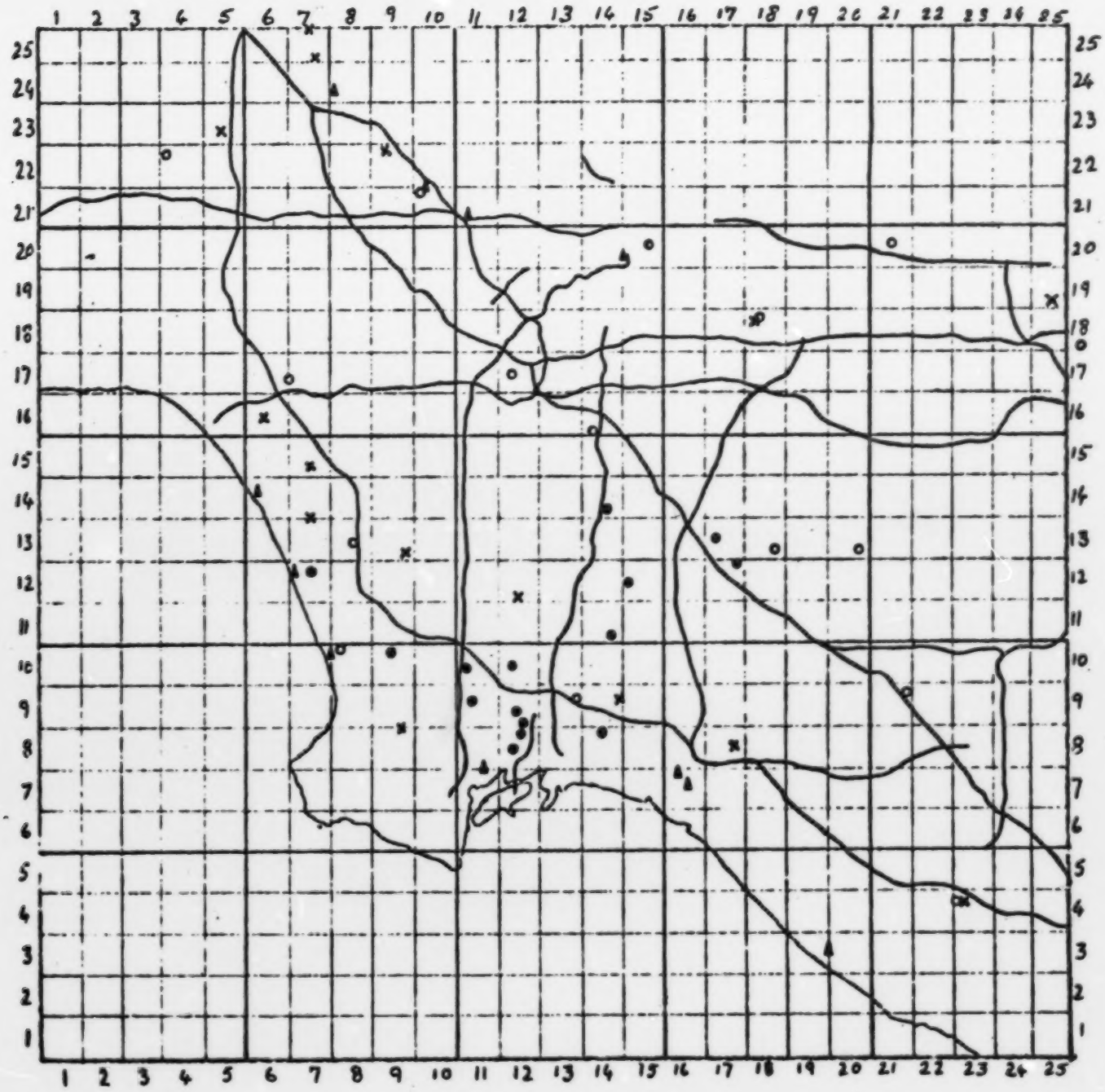

Figure A-1. Location of Primary Sources and Monitoring Stations in the Los Angeles Basin

- freeways
- oil refineries
- power plants
- airports
- contaminant monitoring stations

a particular urban area. In a study published in 1955, Larson, et al. (a paper often incorrectly attributed to D. M. Teague) describe an inventory undertaken for the County of Los Angeles. In this effort, emissions rates were measured for a number of vehicles, and traffic count data were used to obtain the geographical and temporal distribution of traffic in the area. Ozolins and Smith (1968) discuss a procedure based on gasoline sales figures, traffic flow maps and average emissions rates to obtain total daily vehicle emissions and an approximate measure of their spatial variation over an area. Rehmann (1968) performed an inventory for Gary, Indiana, using for emissions data the results of a study reported by Rose, et al. (1965). [Vehicle emissions rates reported by Rose (and obtained from tests on 1955-1963 automobiles) are presented as a function of average route speed.] Rehmann assumed in his study that emissions from a vehicle are a function only of its average speed. He used traffic counts and traffic flow maps, along with estimates of average speeds on different classes of streets, to obtain the spatial variation of automobile emissions in the city. Lamb (1968) compiled an inventory of the Los Angeles Basin in a manner similar to that of Rehmann. Lamb, as Rehmann, adopted the emissions figures published by Rose. He also applied an average temporal distribution of traffic flow to obtain the variation of emissions through the day. However, Lamb did not include in his report the geographical distribution of traffic which he derived.

For the purpose of our modeling venture, the effort to obtain an accurate vehicle emissions inventory of the Los Angeles Basin was separated into two detailed studies:

(1) Estimation of spatial and temporal distribution of traffic; and

(2) Estimation of average vehicle emissions rates applicable to traffic in the area.

Geographical and temporal variations of vehicle emissions in the area were then derived, based on the results of these studies.

As there have been no recent results published regarding the spatial distribution of traffic in the basin, we undertook our own study based on existing traffic count data. These data were obtained from nearly 100 municipalities and are very extensive, with counts being available for all but minor residential streets. The modeling area (50 miles square) was divided into 625 grid squares of 2x2 miles each. Using the traffic count data, estimates were made of the vehicle miles driven per day in each two mile square area. Although this part of the study required a large and time consuming effort, it was considered to be worthwhile as the results should be valid for several years, with only occasional updating. The temporal distribution of traffic over the area, represented as hourly variations in vehicular flow, was also computed from these count data. Freeways and surface streets were treated separately in the derivation of both the temporal and spatial distributions.

The automobile emissions data used in our study are those published by the State of California Air Resources Board (ARB). These data are based on emissions measurements made by the ARB on a sample of approximately

7,500 automobiles of model years 1966 to 1969, and on measurements made under a joint Federal/State/City program on a sample of approximately 1,000 pre-1964 model year automobiles. These data are well suited to an inventory of the Los Angeles Basin, as the emissions measurements were made on privately owned cars actually operated in the area. However, while the driving cycle used by the ARB in measuring automobile emissions is based on a typical Los Angeles commuter run, the degree to which it is actually representative of vehicle emissions patterns is not known. (See page A-19 for a discussion of this question.) Finally, by using a test procedure based on a driving cycle, it is possible to express the emissions rate of each contaminant as a single figure. This figure, as we have suggested, takes into account the effects on emissions of the different driving modes in which vehicles are actually operated. This method of expressing emissions obviates the necessity of estimating average route speeds, which would require a street classification scheme.

In the sections that follow we first describe the automobile emissions model adopted. We then summarize the major results of the emissions inventory: spatial and temporal distributions of traffic and vehicle emissions rates. Finally, the calculational procedures and data used in the study are detailed.

A. Automobile Emissions Model

Emissions are attributable to the following three sources in an uncontrolled automobile:

(1) *Exhaust* emissions account for approximately 65% of hydrocarbons and 100% of nitrogen oxides and carbon monoxide;

(2) *Crankcase* leakage (or blow-by) accounts for approximately 20% of hydrocarbons;

(3) *Evaporation* from the fuel tank and carburetor accounts for approximately 15% of hydrocarbons.

As a result of vehicle modifications and changing legislation for automobile emissions through the 1960's, the magnitudes and relative contributions of these three sources vary with vehicle model year.

In this section we present a model for each of these three automobile emissions sources. Average pollutant emissions rates of Los Angeles Basin vehicles are then calculated, and the results presented in summary form. Emissions rates are expressed in grams/mile for exhaust and blow-by, and grams/day for evaporation. The flux of emissions into a grid square resulting from exhaust and blow-by is then simply the product of the emissions rate and the number of vehicle miles driven per time period in that square. The total daily evaporative loss from all vehicles in the basin is estimated, and is distributed in proportion to the daily non-freeway vehicle mileage driven in each square. As the estimation of daily vehicle mileage was a substantial undertaking, we describe in some detail the means by which these estimates were derived.

1. Exhaust emissions

The emissions rate of species k from the exhaust of an average automobile in the Los Angeles Basin, in grams per mile, is given by:

$$Q_k = \sum_{i=1}^{5} x_i \sum_{j=1}^{4} y_{ij} e_{ijk} K_{ijk}$$

where

x_i = fraction of total cars in the Los Angeles Basin of model year i

where

$i = 1$ up to and including 1965
2 1966
3 1967
4 1968
5 1969

T = total number of cars in Los Angeles Basin in Fall 1969

y_{ij} = fraction of $x_i T$ manufactured by

$j = 1$ General Motors Corporation
2 Chrysler Corporation
3 Ford Motor Company
4 Foreign Manufacturers

e_{ijk} = volumetric exhaust emissions rate of species k from cars manufactured by maker j of model year i

where

$k = 1$ CO (in %)
2 Hydrocarbons (in ppm)
3 NO_x (in ppm)

K_{ijk} = constant from table; a multiplier to convert ppm (or %) to grams per mile

= $f(W_{ij})$ where W_{ij} = average weight of car in model year i manufactured by jth manufacturer.

Assumptions:

(1) The California Driving Cycle is representative of driving in the Los Angeles Basin. (See page A-19 for a discussion of this point.)

(2) Emissions rates based on the California Driving Cycle can be taken as average emissions for automobiles traveling on surface streets and freeways.

(3) Emissions rates, e_{ijk}, in addition to being a function of manufacturer and model year, are a function of average vehicle mileage and are independent of engine size. (The latter assumption has been confirmed through analysis of emissions data.)

(4) All automobiles travel about 11,000 miles per year, and all were purchased at the middle of the model year--about March 1-April 1.*

Formulation of the model in this way enables us to take advantage of the vast data base amassed by the California State Air Resources Board (ARB) in recent years.

Calculation of average automobile emissions rates is based on data relating to cars comprising approximately 90% of the total registration in Los Angeles and Orange Counties. Of this 90%, however, approximately 65% (i.e., 59% of the total) are pre-1966 models for which only overall average emissions figures are available. The other 10% of the automobile registration consists mainly of pick-ups and AMC automobiles, none of which could be included, due to an absence of emissions data. Division of the vehicle population by manufacturer was made only to take advantage of correlations derived by the ARB through regression analysis.

For a given grid square, the grams of species k emitted as engine exhaust per hour (for the ℓ^{th} hour) into a cell (or assignable to a node at the center of a cell) =

$$\left(Q_k \frac{\text{grams}}{\text{vehicle mile}}\right)\left(M_\ell \frac{\text{vehicle miles}}{\text{hour}}\right)$$

*Calculations are made as of October 1, 1969. Thus, average automobile mileages are as follows:

Vehicle Model Year	Odometer Reading (miles)
1969	5,000
1968	16,000
1967	27,000
1966	38,000
1965 and older	> 50,000

Emissions calculations are based on these average mileages, as taken from regression analyses (presented as emissions of species k from a vehicle of model year i as a function of mileage) reported by Hocker (1970a, 1970b).

Calculation of M_ℓ:

For surface streets--

$$M_\ell = d_\ell \sum_{u=1}^{s} n_u t_u$$

where

n_u = vehicles per day (given as traffic counts at a point, assignable to a segment of road)

t_u = miles of road segment to which count n_u is assigned

d_ℓ = fraction of daily (24-hour) traffic count assignable to hourly period ℓ

s = number of road segments contained in the grid square.

For freeways--

Same calculation, using different distribution, d_ℓ.

Traffic counts for virtually all freeways, arterials, and main streets are available. Counts for minor residential streets are sparse and are thus estimated.

The data base consists of counts made by

(a) State of California for freeways and state highways

(b) Los Angeles County for small towns and unincorporated areas

(c) Municipalities

(1) Los Angeles County--about 70 incorporated cities
(2) Orange County--about 20 incorporated cities

2. Crankcase emissions

Positive Crankcase Ventilation (PCV) devices have been installed on automobiles in recent years to prevent the loss of hydrocarbons to the atmosphere resulting from leakage between the piston and cylinder during the compression stroke. As these devices recycle crankcase fumes through the carburetor air intake, blow-by

losses from properly equipped vehicles have been virtually eliminated.

California law requires that PCV devices be fitted to all autos

- of domestic manufacture of model year 1963 and later
- of domestic manufacture of 1955-1962 vintage upon change of ownership
- of foreign manufacture of model year 1965 and later.

However, these devices were installed on new domestic cars sold in California as early as 1961, and the law concerning 1955 to 1962 model years became effective in 1964.

Since it is estimated that only 15% of all automobiles are not equipped with PCV valves, crankcase losses contribute but a small fraction of total emitted hydrocarbons. Our estimated figure for blow-by losses (see Section 3 of Part C for details) is 0.7 grams/mile for the average vehicle in the Los Angeles Basin.

3. Evaporative losses

Evaporative losses occur at the fuel tank and the carburetor and involve only hydrocarbons. These losses have been estimated at approximately 72 grams/day (See Part C, section 3 for details). While tank losses occur primarily during vehicle operation and carburetor losses during the periods after a hot engine is stopped, elevated daytime temperatures and exposure to the sun serve to enhance evaporation rates. In the absence of definitive data we have chosen to distribute the daily loss evenly between the daylight hours of 7 a.m. to 7 p.m. PDT (6 a.m. to 6 p.m. PST), assuming nighttime evaporative losses to be small.

The total evaporative loss from over 4.1 million vehicles at a rate of 6 grams/vehicle/hour is distributed over the Basin area in proportion to the non-freeway vehicle mileage in each grid square (*total* daily non-freeway vehicle mileage for the Basin $\cong 72.4 \times 10^6$). We believe that this distribution approximates actual vehicle distribution (fixed and moving) as closely as any distribution available. Under this assumption, evaporative emissions for each grid square equal $0.343 m_{ij}$ kilograms/hour, where m_{ij} = thousands of non-freeway vehicle miles per day driven in square ij.

B. Summary of Major Assumptions and Presentation of Results

The major assumptions on which the model formulation is based are summarized as follows:

(1) Automobile emissions may be represented by the results of tests using the hot start California Driving Cycle. Furthermore, these emissions may be expressed as "lumped" or "single figure" rates

for Los Angeles Basin traffic, independent of average speed, modal split, etc.

(2) All arteries, freeways and surface streets may be treated as area sources. (This assumption is questionable in the case of freeways and will be examined in depth during exercise of the overall model.)

(3) Emissions rates for all vehicles in the basin are typified by the data obtained from the 8500 automobiles and 135 trucks tested. This sample excludes many imports, automobiles produced by the smaller domestic manufacturers, and all 1964 and 1965 autos.

(4) The temporal distributions estimated for freeways and surface streets may be applied to the total daily vehicle mileages calculated for each grid square.

The major results of the automotive emissions inventory are now presented.

Area surveyed: 50 mile x 50 mile, predominantly urban area having as its boundaries:

longitude	west	118°	38'	15"
	east	117°	46'	3"
latitude	north	34°	17'	30"
	south	33°	34'	2"

The area is divided into 625 grid squares, each 2 miles x miles.*

Spatial distribution of traffic, $\sum_u n_u t_u$, *for each grid square:*

freeways	Figure A-2
non-freeways	Figure A-3

Temporal distribution of traffic, d_ℓ:

freeways	Figure A-4 and Table A-1
non-freeways	Figure A-4 and Table A-1

Emissions rates, Q_k: Table A-2

*For further reference, the center of the area, 25 miles from each border, lies on Century Boulevard, 0.1 mile south of its intersection with Imperial Highway, in the City of Linwood.

Figures A-2 to A-4
and Tables A-1 and A-2 follow

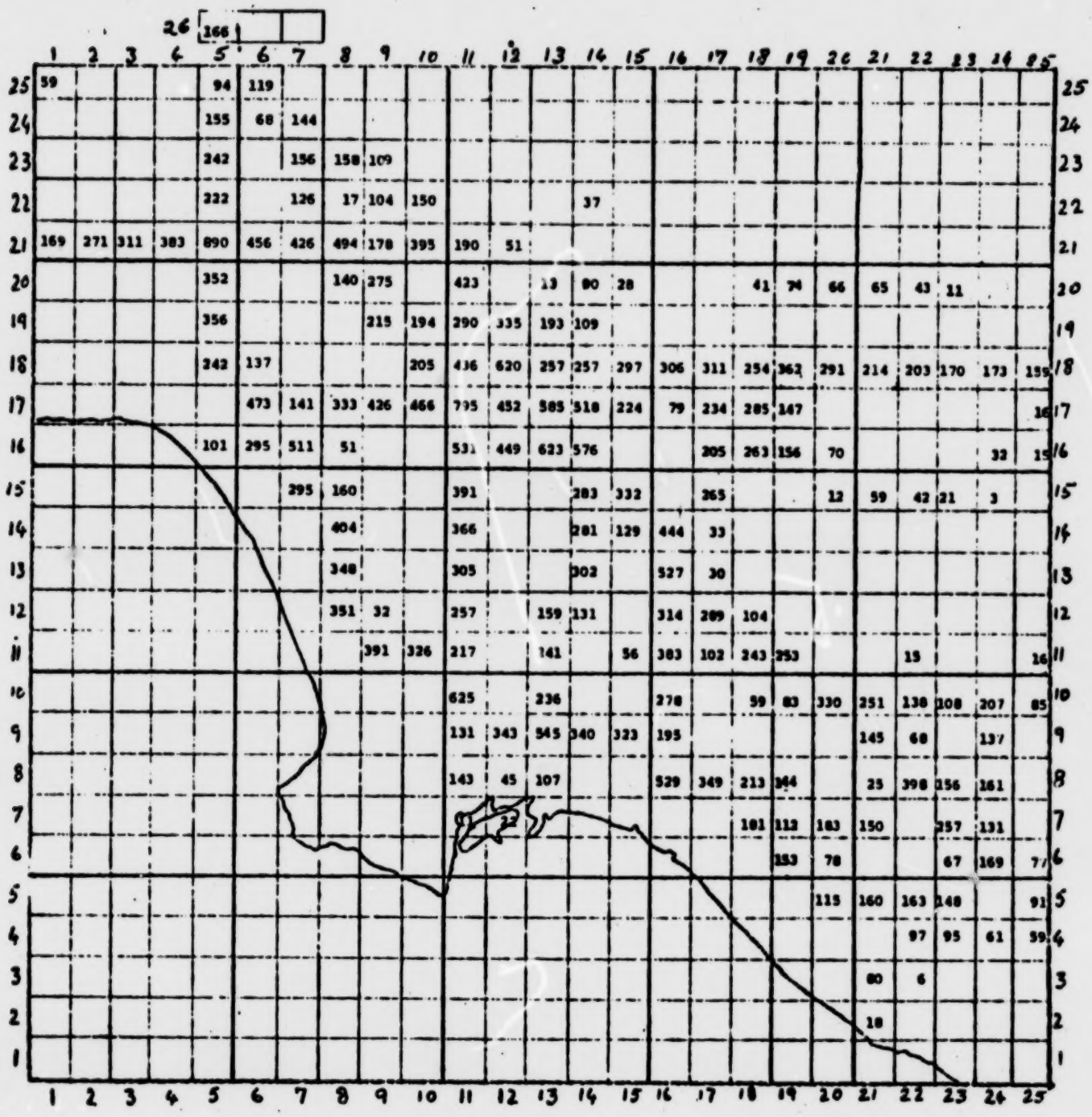

Figure A-2. Spatial Distribution of Freeway Traffic
(thousand vehicle miles per day)

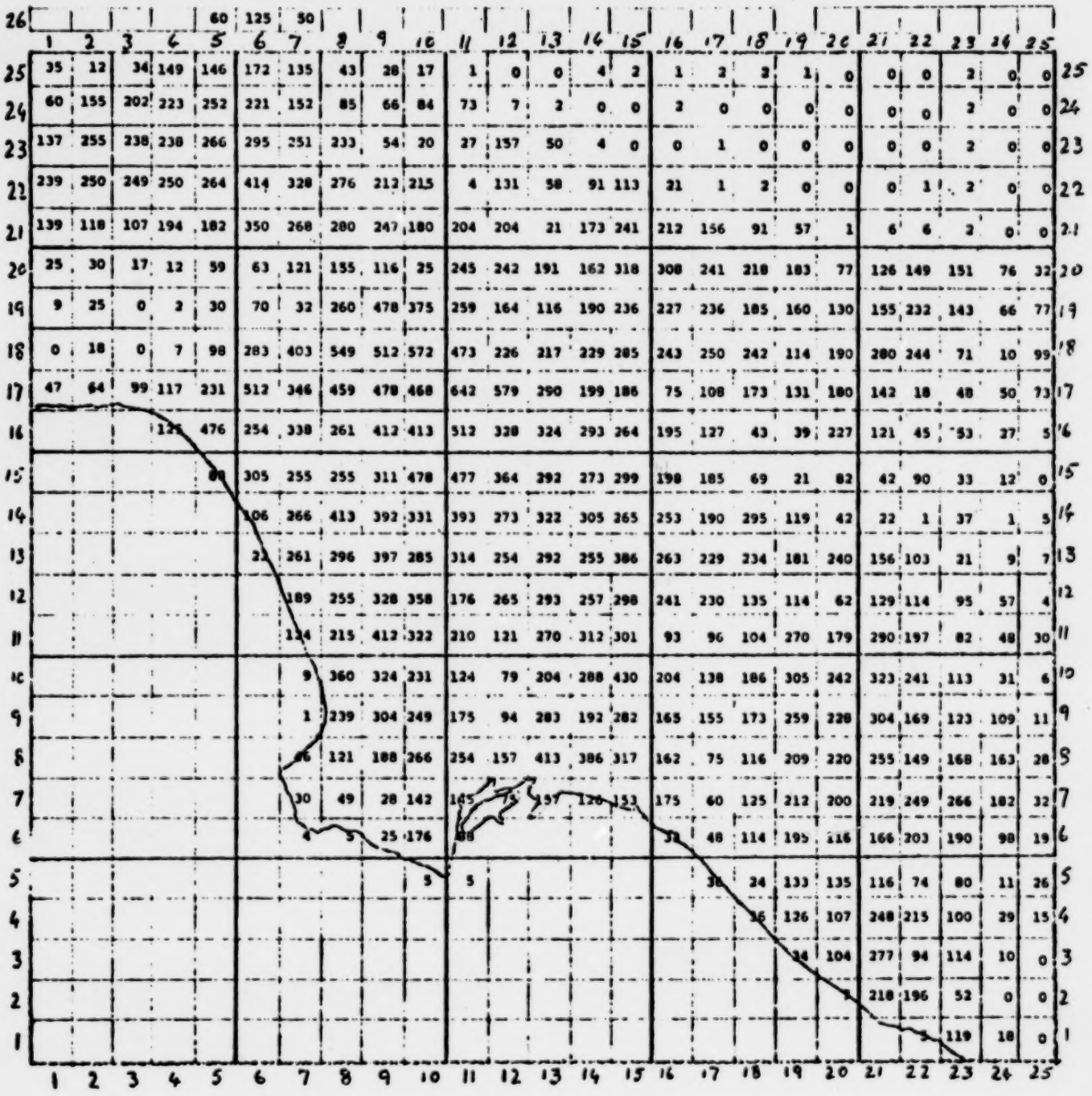

Figure A-3. Spatial Distribution of Non-Freeway Traffic
(thousand vehicle miles per day)

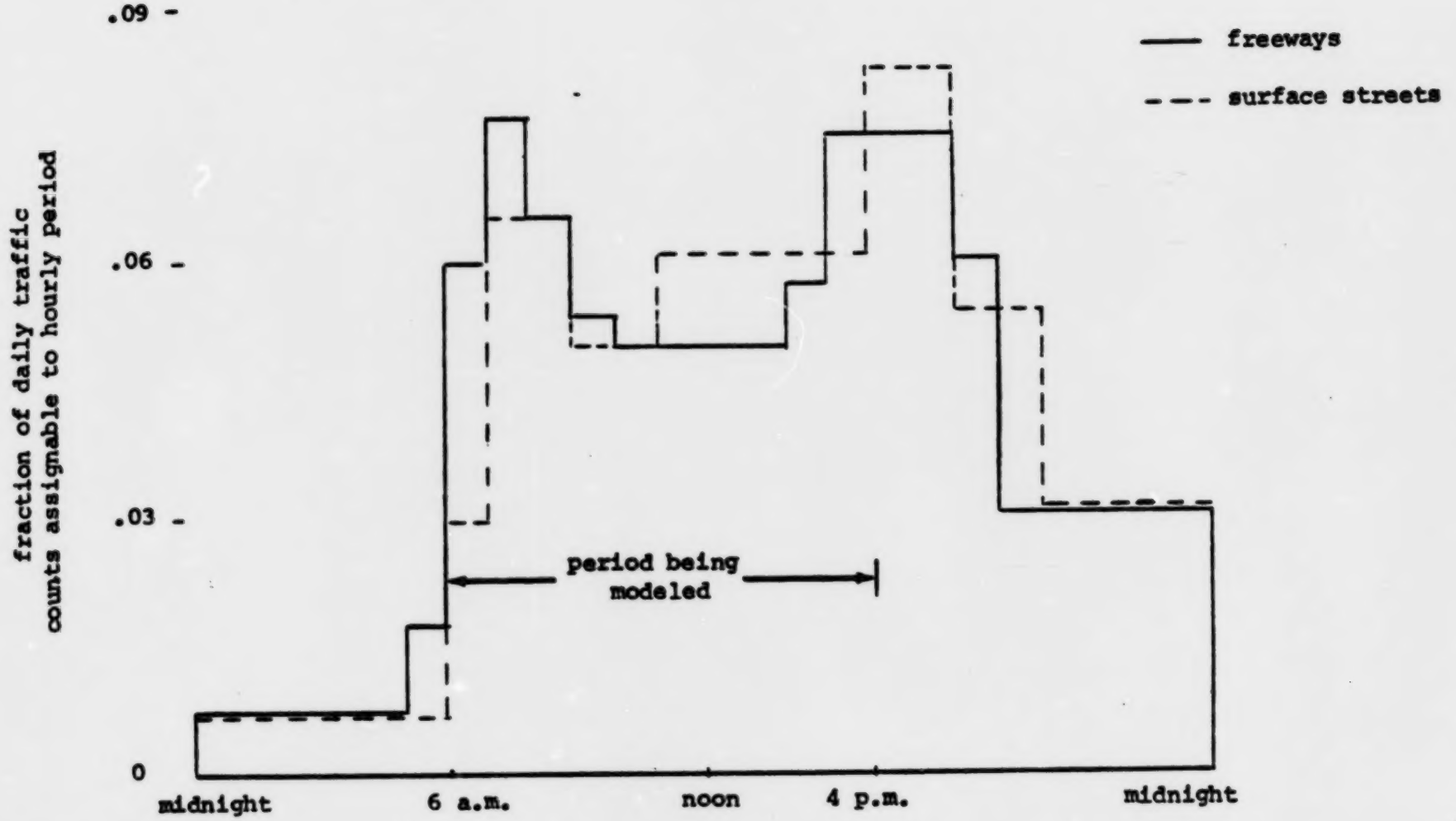

Figure A-4. Temporal Distribution of Traffic for Freeways and Surface Streets

Table A-1. Temporal Distribution of Traffic

Hourly Period* (local time)	Fraction of Daily Traffic
Freeways	
12-5 a.m.	.0388
5-6	.0178
6-7	.0591
7-8	.0768
8-9	.0648
9-10	.0536
10 a.m.-2 p.m.	.1977
2-3	.0569
3-6	.2238
6-7	.0598
7-12	.1511
Surface Streets	
12-6 a.m.	.0407
6-7	.0293
7-9	.1302
9-11	.1004
11 a.m.-4 p.m.	.3044
4-6	.1639
6-8	.1081
8-12	.1231

*Distributions are approximately uniform for the *daylight* time periods indicated. However, traffic is not uniformly distributed within the periods 7 p.m. to 5 a.m. for freeways, 8 p.m. to 5 a.m. for surface streets. These groupings are included only for completeness.

Table A-2. Vehicle Emissions Factors - Q_k[+]

Exhaust:

Q_{CO}	63.9 grams/vehicle mile
Q^*_{HC}	8.3 grams/vehicle mile
Q_{NO_x}	4.4 grams/vehicle mile

*Additions to Q_{HC}

blow-by	0.7 grams/vehicle mile
evaporation**	72.0 grams/vehicle/day

+Computed for the average vehicle in the Los Angeles Basin as of September 1969. Automobile exhaust emissions are based on hot start California Driving Cycle. See page A-26 for a comparison of these emissions factors with those based on the 1972 Federal test procedure.

*Hydrocarbon emissions: 85% reactive, 15% unreactive. (See Table A-10.)

**Computed as $343m_{ij}$ grams/hour for each grid square for the period 7 a.m.-7 p.m. PST, where m_{ij} is thousands of non-freeway vehicle miles/day driven in square ij; no emissions for the nighttime period, 7 p.m.-7 a.m.

C. The Calculations and Data Sources

In this section, we will describe in some detail the calculational aspects of the automotive emissions inventory, as well as data sources.

1. Spatial distribution of traffic

The major question of strategy in planning the computation of the spatial distribution was whether the calculations should be carried out manually or by computer. A cursory analysis indicated that the cost of computerization far exceeded that for manual calculations. Unless the computer-based procedures were to be exercised repeatedly, manual computations were clearly favored. It should be mentioned that the Bureau of the Census is currently developing a map encoding technique known as DIME (Dual Independent Map Encoding) which, when available, can be extended and modified for use in the analysis of automotive emissions. However, the DIME file for Los Angeles, according to current estimates, will not become available for some time.

The second strategic issue involved the level of detail we wished to incorporate into the procedure. Were we to include traffic counts only for freeways and major and minor arteries, ignoring residential and side streets, or were we to include all streets? Since this effort was to be undertaken only once, we were inclined to make as complete an inventory as possible. However, there exists a dearth of data for the smaller streets, so we compromised by adopting the policy of using all available counts and estimating traffic flow on the remaining streets from the local traffic data in the area, the type of neighborhood, and reference to counts on similar streets.

We began by acquiring the U.S. Geological Survey topographic maps (7 1/2' series) of the 50 mile x 50 mile area encompassing the Los Angeles Basin and ruling off 625 2 mile x 2 mile grid squares. For each grid square, a team of two students each, using roadmaps and vehicle count data (acquired from the state, two counties, and 90 municipalities), filled in worksheets such as that shown in Figure A-5. The pair of students would enter all mileages and counts on the sheet, a third student would do all multiplications and additions, and a fourth would quickly check for accuracy. Two to four teams, along with one or two students carrying out the computations, were involved throughout the seven-week effort. Freeway computations were carried out and recorded separately. The total effort involved over 1400 man-hours of student labor, excluding the time required for formulation of the model, organization of the effort (including hiring and administration), preparation of maps, and the substantial effort required for acquisition of data. In contrast, the more extensive effort (estimated time: six to twelve months) of creating a computerized data base and automating the manual procedure would have represented a cost 25 to 50 times that incurred. (If the DIME file were available at the inception of the project, estimated costs would have exceeded incurred costs by a factor of 3 to 8.)

Figure A-5 follows

SQUARE 9-17 NORTH / SOUTH

478 492 = TOTAL FOR SQUARE

STREET ON WHICH TRAFFIC IS COUNTED	FIRST INTERSECTION	SECOND INTERSECTION	TABULATED TRAFFIC COUNT ♦	TRAFFIC COUNT TO BE USED IN COMPUTING (ACTUAL or AVG)	MILES	VEHICLE MILES PER DAY
La Brea	Edge	Olympic	28590	28590	.25	7148
	Olympic	Pico	41506	35048	.65	22781
	Pico	Venice	44605	43056	.1	4306
	Venice	Washington	48142	46374	.4	18550
	Washington	Adams	53400	50771	.65	33001
	Adams	Edge	53400	53400	.05	2670
Crenshaw	Edge	Pico	22511	22511	.25	5628
	Pico	Washington	33114	27813	.65	18078
	Washington	Adams	44811	38963	.6	23378
	Adams	Edge		44811	.05	2241
Hauser	Edge	Olympic	7,943	7943	.25	1986
	Olympic	San Vicente	8,322	8133	.25	2033
	San Vicente	Pico	9,603	8913	.4	3565
	Pico	Venice	11,080	10292	.3	3088
DUNSMUIR	N/o Washington		108	108	1.75	189
COCHRAN	Edge	Olympic	5,608	→	.25	1402
	Olympic	San Vicente	4,970	5289	.3	1587
	San Vicente	Pico	6,067	5519	.3	1656
	Pico	Venice	3,447	4757	.25	1189
CLOVERDALE	(Wilshire) Packard		2,179	2813	1.5	4220
			475	— o —		— o —
Meadowbrook	Packard		499	499	.85	424
Redondo	Olympic	San Vicente	9,360	→ 9360	.45	4212
	San Vicente	Pico	11,051	10206	.25	2552
	Pico	Venice	12,409	→ 11730	.2	2346
	Venice	Washington	9,553	10981	.3	3294
	Washington	Adams	8,051	8802	.8	7042
ORANGE	12th		409	409	2.05	838
Highland	Olympic	8th	14,620**	— o —		— o —
			15,000	14810	.3	4443
	The Rest		500**	500	1.2	600

Total VMPD 184 447 CP

Square 9-17

Check Calculation 184447

Page 1 of 4

♦ If Manual, mark *

If Estimate, mark **

Initials

Figure A-5. Typical Worksheet Used in the Computation of Vehicle Mileage

We estimate that $\Sigma n_u t_u$ for each grid square is almost certainly accurate to ±10% and very likely to ±5% or less. Thus, a figure of 400,000 vehicle miles/day should be read 400,000 ± 20,000. Finally, all worksheets and raw data have been preserved and are available to those interested.

2. Temporal distribution of traffic

It is commonly accepted that the hourly variation in weekday traffic flow may be represented over a 24-hour period by a bimodal distribution having peaks at the morning and afternoon rush hours and a high plateau between these peaks. However, the parameters needed to describe this distribution--the height of each peak, the height of the plateau, the time interval encompassing each peak--vary from street to street. Shopping areas have a high frequency of traffic between peak hours. Streets in lower middle class neighborhoods experience earlier morning and afternoon peaks than do streets in upper middle class neighborhoods. Downtown streets carry light traffic following the afternoon peak, whereas suburban and residential arterials have higher traffic loads at this time. Ideally then, one would like to classify streets in accordance with a workable identification scheme, applying an appropriate distribution for each class.

Classification was more easily postulated as theory than applied in practice. We examined classifications of streets according to geographical area, type of street (business, residential, warehouse, etc.), and distance from major working centers, all with a notable lack of success. The first and third classification schemes were probably unsuccessful because of the large number of employment centers in Los Angeles. Most large cities experience morning flows into vs. out of town (and afternoon flows out vs. into town) in ratios of between 2 and 3 to 1. In Los Angeles the ratio is more nearly 1 to 1. The second scheme suggested proved most difficult to implement, as the effort of classification is so large.

Prior to examining classification schemes, however, we tested the hypothesis that the traffic counts on 25 randomly selected streets (stratified with respect to the magnitude of daily traffic flow) represent draws from a common population--the "grand" distribution.* As might be inferred from our need to examine classification schemes, the variability among the distributions of traffic on the various streets was sufficiently great that, on statistical grounds, traffic flows could not be represented by a "grand" distribution. However, we soon realized that the 2 mile x 2 mile grid squares, the smallest spatial unit under consideration, commonly contained streets of many classifications. Why not develop a "grand" distribution which, if not statistically justified from street to street, was applicable to groupings of streets defined by the grid system?

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*Data were taken from the 24-hour traffic count sheets of the City of Los Angeles Department of Traffic. Counts were summarized as number of vehicles passing over a pneumatic tube for each 15-minute interval throughout the day. For our analysis we lumped these statistics into hourly intervals.

In order to examine this question, we first derived an hourly distribution of vehicle counts (i.e., the fraction of daily traffic assignable to each of 24 hourly periods) based on an average of 52 randomly selected city streets (again, the sample being stratified according to the magnitude of daily traffic flow), the counts on individual streets being weighted in proportion to the magnitude of traffic flow on the street. The resulting distribution was then multiplied by total vehicle mileage per day for a particular grid square. These *calculated* hourly vehicle mileages were then compared with hourly vehicle mileages for the same grid square, determined using *actual* hourly traffic counts. The calculated discrepancies in vehicle mileage for each time period for the prototype grid square are:

Time Period*	Discrepancy	Approximate Percentage of Daily Traffic Flow
6-7 a.m.**	-10.5%	3%
7-9 a.m.	0.3	13
9-11 a.m.	- 7.0	10
11 a.m.-4 p.m.	4.0	30
4-6 p.m.	- 6.0	16
6-8 p.m.	- 3.1	11

Given the levels of error inherent in establishing photochemical reaction rates, wind fields, and inversion heights--largely due to a paucity of data--we believe that the magnitudes of these discrepancies fall within acceptable limits. (Note: Traffic flows for the 6-7 a.m. period are highly variable. While the 10.5% discrepancy is somewhat large, its net effect will be small due to the low traffic flow characteristic of the time period).

The temporal distribution for freeways, not considered as a part of the analysis just described, was more easily treated. We were able to acquire 15 minute count data for a 24-hour period at 31 locations scattered throughout the Basin. As counts were available for 7 to 14 day periods, we computed an average figure for the Monday to Thursday period. These averages exhibited only minor variations when compared to an overall computed average temporal distribution. Thus, this overall distribution was taken as representative of temporal variations in traffic flow on the freeways. The temporal distributions for both freeways and non-freeways are shown in Figure A-4 and Table A-1.

As was the case for the spatial distribution of traffic, all calculations, worksheets, and data have been preserved and are available to those interested.

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*Local time. PDT when daylight savings time is in force, PST at other times.

**Note: Hourly traffic counts remain approximately constant within the time intervals listed.

3. Pollutant emissions rates

In this discussion we consider the three major automotive emissions sources. Reference will be made to x_i, y_{ij}, e_{ijk}, K_{ijk}, and W_{ij}, as defined in section 1 of Part A describing the model.

Exhaust

Several test procedures for measuring exhaust emissions have been proposed in recent years. These procedures have as their common aim the simulation of emissions in a stationary test of a vehicle being operated in traffic. There is currently considerable debate concerning the degree to which the various test procedures are representative of actual vehicular emissions, or, indeed, if it is possible to simulate the emissions of a vehicle by any test procedure. A choice must also be made between the use of a hot start and a cold start procedure.

A method which has enjoyed widespread use in recent years, including adoption as the Federal testing procedure up to 1971, is the California Driving Cycle (CDC). This is a seven-mode test procedure and is based on a Los Angeles commuter run (see State of California ARB (1968)). Recently, however, the representativeness of the CDC has been questioned, and a new method, the 1972 Federal test procedure, has been proposed. This procedure employs a cold start and a driving cycle (the LA-4 cycle) derived from a Los Angeles driving route during heavy traffic periods. Actual mass emissions are monitored over the entire driving cycle, in contrast to the CDC, in which concentrations are measured. The differences between the three procedures -- hot start and cold start CDC and 1972 Federal procedure -- are illustrated by the following figures (Sigworth (1971)):

	Approximate increase in emissions rates when measured by cold start CDC, as compared with hot start CDC (all vehicles).	Approximate increase in emissions rates when measured by 1972 Federal procedure, as compared with *cold start* CDC.	
		Pre-1966 vehicles	1966-1969 vehicles
HC	+30%	+40%	+90%
CO	+0-10%	+60%	+100%
NO_x	- 5%	+60%	+30%

It is apparent from these figures that measured emissions rates are strongly dependent on the testing procedure employed.

The purpose of this effort is to estimate an average emissions factor applicable to vehicles operating on both surface streets and freeways in the Los Angeles Basin. It was felt that data obtained using the 1972 Federal procedure, which was derived for heavy traffic conditions, would result in inflated emissions rates when applied to the whole basin. We thus based our calculations on data obtained using the hot start CDC. We present in comparison, however, emissions factors based on the 1972 Federal test procedure, which were derived by the Air Pollution Control Office, Environmental Protection Agency. In the discussion that follows, calculational aspects central to the estimation of exhaust emissions factors are outlined.

The total motor vehicle registrations for Los Angeles and Orange Counties by make and model year are shown in Table A-3. The total of pre-1958 autos was estimated from the California car age distribution, Figure A-6, to be 12% of the total registration, and this figure was distributed among the four manufacturers in proportion to their total registrations from 1958 to 1969, less weight being given to imported models. Note that the age distribution given in Figure A-6 is derived from 1967 data, as these are the most recent data available; it was thus necessary to assume that the age distribution has not changed between 1967 and 1969. x_i and y_{ij} were computed directly from Table A-3, and the results are shown in Table A-4.

The values of the volumetric exhaust emissions factors e_{ijk} were then estimated, using the data published by Hocker (1970a, 1970b) and the mileage assumptions outlined in Section A1. These values of e_{ijk}, shown in Table A-5, are weighted according to the California car population. For example, the emissions figures shown for Ford vehicles are weighted in proportion to the numbers of Lincolns, Mustangs, etc., sold in California, so as to account for different emissions rates from these models.

The values of the conversion factors to convert exhaust volume emissions rates to grams/mile are given as a function of automobile weight and are different for a vehicle equipped with automatic transmission from one equipped with manual transmission (see Table A-8). The average automobile weights, W_{ij}, are shown in Table A-6. The figures given are weighted in proportion to the number of a particular automobile type sold by each manufacturer, as reflected by the national new car registrations for that year.

To calculate K_{ijk} $(= f(W_{ij}))$, we write:

$$K_{ijk} = \nu_{ij} K^{A}_{ijk} + (1 - \nu_{ij}) K^{M}_{ijk}$$

where

K^{A}_{ijk} = constant for automatic transmission, Table A-8

K^{M}_{ijk} = constant for manual transmissions, Table A-8

ν_{ij} = fraction of cars by jth manufacturer of model year i having automatic transmissions.

Figure A-6 and
Tables A-3 to A-8 follow

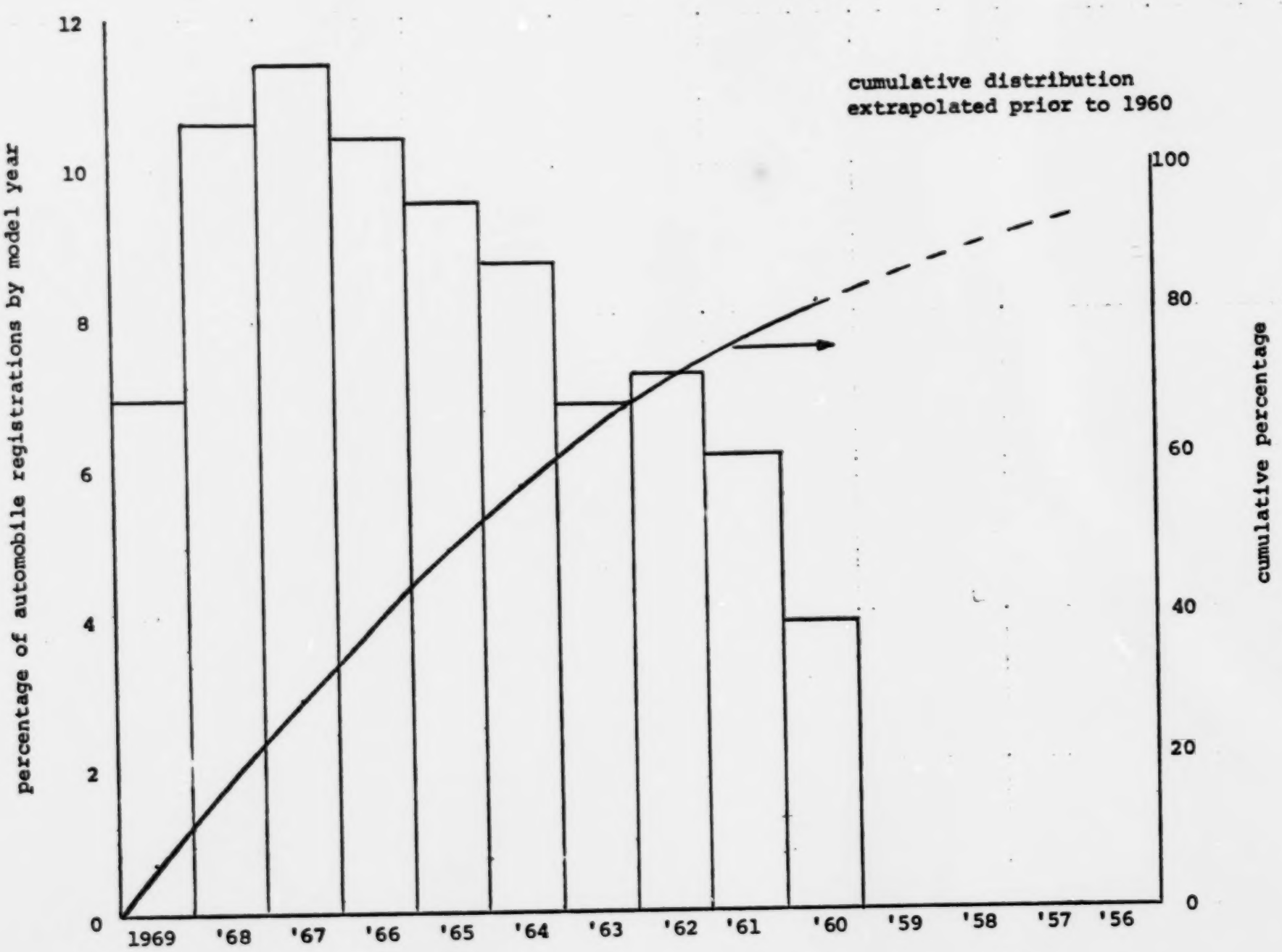

Figure A-6. Age Distribution of California Automobiles
(1967 registration figures, updated to 1969)
[Taken from "Automotive Industries," March 15, 1968, p. 114]

Table A-3. Total Vehicle Registrations in Los Angeles and Orange Counties*
(As of September 30, 1969)

Manufacturer \ Model year	Pre-1958 (Approx.)	1958-1965	1966	1967	1968	1969
General Motors Corporation	233,723	948,665	156,550	143,327	127,866	75,197
Chrysler Corp.	63,568	227,571	48,955	43,529	47,960	22,530
Ford Motor Company	138,927	545,338	112,555	94,338	64,611	41,144
Foreign	60,000	244,220	66,208	79,774	77,163	57,205

	Total	3,720,924
Automobiles manufactured by General Motors, Chrysler, Ford, and foreign corporations not included above (out of state, not running, etc.)		110,110
Automobiles manufactured by American Motors Corporation, Studebaker Corporation, Kaiser Jeep Corporation, Checker Motors		154,543
Miscellaneous		18,619
Unaccounted for (pick-ups, campers, etc.)		130,956
	Total	4,135,152

In addition:

Motorcycles	176,139
Trucks	548,092

*Department of Motor Vehicles, State of California

Table A-4. Fraction of the Total Automobiles in the Los Angeles Basin, by Model Year and Manufacturer

i	x_i		y_{ij} i = 1	2	3	4	5
1	0.662	j = 1	0.480	0.407	0.397	0.403	0.384
2	0.103	2	0.118	0.127	0.120	0.151	0.115
3	0.097	3	0.278	0.293	0.261	0.203	0.210
4	0.085	4	0.124	0.124	0.221	0.243	0.292
5	0.053						

x_i = fraction of total cars in the Los Angeles Basin of model year i

where i = 1 up to and including 1965
2 1966
3 1967
4 1968
5 1969

T = total number of cars in Los Angeles Basin in Fall 1969

y_{ij} = fraction of $x_i T$ manufactured by

j = 1 General Motors Corporation
2 Chrysler Corporation
3 Ford Motor Company
4 Foreign Manufacturers

Table A-5. Concentrations of Volumetric Automobile Exhaust Emissions, e_{ijk}*

			i = 1 (pre-1966)	2 (1966)	3 (1967)	4 (1968)	5 (1969)
j = 1 (General Motors)	k = 1	(CO, %)	3.00	1.46	1.17	1.27	1.12
	2	(HC, ppm)	850	300	274	285	250
	3	(NO_x, ppm)	1075	1430	1480	1415	1525
2 (Chrysler)	1		3.00	1.65	1.40	1.10	0.75
	2		850	375	330	278	245
	3		1075	1390	1535	1600	1665
3 (Ford)	1		3.00	1.57	1.37	1.05	0.68
	2		850	360	320	295	260
	3		1075	1540	1370	1495	1720
4 (Imports)	1		4.05	4.05	4.05	2.23	1.50
	2		1732	1500	1300	526	362
	3		1560	1560	1560	1424	1650

*Data for NO_x emissions from domestic automobiles are obtained from Hocker (1970a), for hydrocarbons and CO from domestic automobiles, from Hocker (1970b). The data for pre-1966 automobiles in these references were taken from a joint Federal, State and Los Angeles City study, carried out in 1963. This study was based on a 1000 car survey of vehicle population at that time. Data for imported automobiles were obtained from A. J. Hocker, California Air Resources Board, private communication.

Table A-6. Average Automobile Weights, W_{ij}*
(in pounds)

j\i	1	2	3	4	5
1	∿3600	3575	3575	3500	3650
2	∿3500	3475	3450	3400	3475
3	∿3300	3225	3325	3375	3500
4	∿2100	2100	2100	2125	2175

Table A-7. Fraction of Automobiles Equipped with Automatic Transmission, ν_{ij}*

j\i	1	2	3	4	5
1	0.75	0.859	0.879	0.898	0.912
2	0.75	0.900	0.917	0.924	0.917
3	0.75	0.819	0.862	0.906	0.882
4	0.00	0.010	0.030	0.060	0.100

*"Automotive Industries," Statistical Edition, published on March 15 of each year.

Table A-8. Multiplication Factors to Convert Exhaust Emission Concentrations to Grams/Mile, Expressed as a Function of Vehicle Weight*

weight (pounds) \ transmission type	Automatic			Manual		
	HC x 10^{-3}	CO	NO_x x 10^{-3}	HC x 10^{-3}	CO	NO_x x 10^{-3}
1500	5.34	10.03	1.64	4.81	9.04	1.48
1750	6.28	11.79	1.93	5.64	10.60	1.73
2000	7.18	13.48	2.20	6.45	12.12	1.98
2250	8.02	15.07	2.46	7.16	13.54	2.22
2500	8.82	16.56	2.71	7.92	14.86	2.43
2750	9.58	17.98	2.94	8.60	16.16	2.64
3000	10.28	19.30	3.16	9.24	17.35	2.84
3500	11.57	21.72	3.55	10.50	19.53	3.20
4000	12.70	23.84	3.90	11.39	21.39	3.50
4500	13.63	25.59	4.19	12.24	22.98	3.76
5000	14.39	27.02	4.42	12.92	24.27	3.97
5500	14.97	28.11	4.60	13.44	25.23	4.13

*State of California Air Resources Board

The values of ν_{ij} are shown in Table A-7 and are weighted in the same manner as W_{ij}. Using the data contained in Tables A-6, A-7 and A-8, the values of K_{ijk} were estimated. The results are shown in Table A-9. Finally, using the figures from Tables A-4, A-5 and A-9, the automobile exhaust emission rates, Q_k, were calculated. They are:

$$Q_{CO} = 51.0 \text{ grams/mile}$$

$$Q_{HC} = 7.9 \text{ grams/mile}$$

$$Q_{NO_x} = 4.0 \text{ grams/mile}$$

In addition to reporting an emissions factor for hydrocarbons, it is necessary in the simulation of atmospheric reactions to consider separately reactive and unreactive components in the exhaust. The composition of automobile exhaust emissions have been determined in tests made by the California Air Resources Board. The results obtained by them are reported as percentages of hydrocarbon components in the exhaust of controlled and uncontrolled automobiles and are shown in Table A-10.

Exhaust emissions measurements made on 135 gasoline powered trucks and buses of all weight classes have been reported by Springer (1969). Using a driving cycle to simulate a Los Angeles truck route, he obtained the following average emissions factors:

$$Q_{CO} = 150 \text{ grams/mile}$$

$$Q_{HC} = 11 \text{ grams/mile}$$

$$Q_{NO_x} = 7 \text{ grams/mile}$$

As trucks comprise 13% of the total vehicle registration in the Los Angeles Basin (Table A-3), the exhaust emissions factors corrected for heavy-duty vehicles, are:

$$Q_{CO} = 0.87 \times 51.0 + 0.13 \times 150.0 = 63.9 \text{ grams/mile}$$

$$Q_{HC} = 0.87 \times 7.9 + 0.13 \times 11.0 = 8.3 \text{ grams/mile}$$

$$Q_{NO_x} = 0.87 \times 4.0 + 0.13 \times 7.0 = 4.4 \text{ grams/mile}$$

Previous comments concerning the representativeness of automobile emissions factors also apply to those for trucks.

In contrast, the Air Pollution Control Office (Sigworth (1971)) has estimated the following exhaust emissions factors to be applicable to the Los Angeles area as of 1969:

$$Q_{CO} = 91.0 \text{ grams/mile}$$

$$Q_{HC} = 11.7 \text{ grams/mile (including blow-by)}$$

$$Q_{NO_x} = 7.0 \text{ grams/mile}$$

Tables A-9 and A-10 follow

Table A-9. Multiplication Factors to Convert Volumetric Exhaust Emission Concentrations to Grams/Mile, K_{ijk}

			i = 1	2	3	4	5
j = 1	k = 1		21.625	21.690	21.734	21.480	22.107
	2	(x 10^{-3})	11.505	11.545	11.567	11.433	11.799
	3	(x 10^{-3})	3.533	3.551	3.558	3.514	3.623
2	1		21.160	21.380	21.299	21.113	21.417
	2	(x 10^{-3})	11.263	11.388	11.309	11.216	11.408
	3	(x 10^{-3})	3.463	3.494	3.482	3.444	3.499
3	1		20.200	20.061	20.593	20.944	21.445
	2	(x 10^{-3})	10.810	10.701	10.965	11.174	11.414
	3	(x 10^{-3})	3.315	3.318	3.371	3.423	3.509
4	1		12.700	12.714	12.743	12.928	13.322
	2	(x 10^{-3})	6.750	6.758	6.773	6.848	7.073
	3	(x 10^{-3})	2.070	2.072	2.077	2.115	2.165

Table A-10. Mean Concentrations of C_2-C_6 Hydrocarbons in Automobile Exhaust*
(based on California Driving Cycle)

Compound	Controlled Cars Composite ppm C	Controlled Cars Composite wt %C	Uncontrolled Cars Composite ppm C	Uncontrolled Cars Composite wt %C
Ethane**	11.3	1.5	27.6	1.4
Ethylene	177	24.1	367	17.8
Acetylene**	98	13.2	252	13.6
Propane	0	0	0	0
Propylene	78	10.5	204	9.9
Isobutane	8.7	1.2	24.3	1.1
Propadiene + Me Acetylene	22.4	3.1	36.4	1.8
n-Butane	39.5	5.5	116	5.5
Isobutene + Butene-1	41.3	5.7	106	5.2
Butene-2, cis & trans	19.2	2.7	76	3.6
Isopentane	77	10.5	242	11.4
β-Methylbutene-1	9	1.2	18	0.9
n-Pentane	42	5.8	129	6.1
Pentene-1	14.5	2.1	50	2.3
Pentene-2, c & t	3.5	0.5	37	1.7
2,2-Dimethylbutane	1.0	0.1	0	0
2-Methylbutadiene-1,3	10	1.5	68	3.1
2-Methylpentane	37	5.0	114	5.4
4-Methylpentene-2	12	1.7	58	2.8
3-Methylpentane	15	2.1	46	2.2
Unidentified	0	0	19	0.9
n-Hexane	13	1.8	52	2.5
Hexene-1	3	0.4	21	1.0
Totals	732	100.2	2090	100.2

*Taken from: "Light Hydrocarbons in Engine Exhaust and the Los Angeles Atmosphere," Air Resources Board, State of California, Fall 1969.
**Assumed unreactive. All other hydrocarbons considered reactive.

These figures are based on the 1972 Federal test procedure, yet were derived from essentially the same emissions data base used by us. It should be understood that while CDC emissions factors have been adopted for the current study, we are unable to assess the degree to which the two driving cycles (or, for that matter, any driving cycle) are representative of actual vehicle performance in a particular locale. Hence, our figures may be subject to revision as more data become available.

Blow-by

The approximate magnitude and composition of blow-by emissions from an uncontrolled automobile are shown in Table A-11.

Estimates of blow-by emissions rate have been made by the Air Pollution Control Office (Sigworth (1971)). Their estimate for the blow-by rate from an uncontrolled automobile (pre-1961 domestic or pre-1965 import) is 4.1 grams/mile. The PCV devices on 1961, 1962, and 1963 domestic vehicles are assumed to be about 80% effective in controlling blow-by; emissions from these vehicles are thus about 0.8 grams/mile. The PCV devices on 1964 and later cars are assumed to be 100% effective, hence there are no blow-by emissions from these vehicles.

Unfortunately, there appears to be no way of finding the number of 1955-1962 domestic autos which have been resold between 1964 and 1969, thus necessitating the fitting of a PCV valve. We have estimated the number of pre-1961 domestic autos fitted with PCV valves to be 60% of the total. Using the vehicle age distribution curve, Figure A-1 and Table A-3, pre-1961, 1961 to 1963 domestic and pre-1965 imported automobiles are seen to comprise approximately 19%, 20%, and 7%, respectively, of the total automobile registration. Hence, blow-by emissions from the average vehicle in the Los Angeles Basin (automobiles comprise 87% of all vehicles) are:

$$0.87\ (0.4 \times 0.19 \times 4.1 + 0.07 \times 4.1 + 0.20 \times 0.8) = 0.7 \text{ grams/mile}$$

Evaporation

Evaporative losses from autos are very difficult to measure and are subject to wide variations in magnitude resulting from different auto operating conditions, weather conditions and automobile design. The subject is discussed by Hurn (1968, page 62), who reports for evaporative losses the figures reproduced in Table A-12. Using Hurn's figures, the total daily evaporative loss per vehicle is:

$$(0.068 + 0.091) \text{ pounds/day} = 72 \text{ grams/day}$$

Tables A-11 and A-12 follow

Table A-11. Estimated Automobile Emissions Attributable to Exhaust and Blow-By*

Component	Blow-By Concentration	Blow-By Weight (pounds/day)	Exhaust Concentration	Exhaust Weight (pounds/day)
CO	Trace	Nil	3.12%	4.160
NO_x	Trace	Nil	850 ppm	0.202
Hydrocarbons				
Paraffins				
C_1-C_5	3150 ppm	0.033	130 ppm	0.034
C_6 & heavier	4780 ppm	0.072	155 ppm	0.073
Olefins				
C_2-C_4	230 ppm	0.001	500 ppm	0.079
C_5 & heavier	1420 ppm	0.017	30 ppm	0.012
Aromatics				
Total less benzene	5150 ppm	0.089	190 ppm	0.100
Benzene	270 ppm	0.003	75 ppm	0.029
Acetylenes	60 ppm	0.001	285 ppm	0.036
Total Hydrocarbons	15060 ppm	0.216	1365 ppm	0.363

*Taken from Hurn, R. W., "Air Pollution," (A. Stern, Ed.), Vol. III, Academic Press, 2nd Edition (1968).

Table A-12. Evaporative Losses From Automobiles*

Component	Hydrocarbons (pound/day) Tank Loss	Carburetor Loss
Paraffins		
C_1-C_5	0.039	0.029
C_6 & heavier	0.010	0.040
Olefins		
C_2-C_4	0.001	0.001
C_5 & heavier	0.013	0.016
Aromatics		
Total less benzene	0.003	0.004
Benzene	0.002	0.001
Total	0.068	0.091

*Taken from Hurn, R. W., "Air Pollution," (A. Stern, Ed.), Vol. III, Academic Press, 2nd Edition (1968).

Carburetor evaporative losses occur mainly during the periods after a hot engine is stopped. The loss during this period is about 18 grams for a 90°F ambient temperature (see Hurn (1968), Figure 5, page 64). Tank losses occur primarily as a result of temperature changes in the tank fuel and in the vapor volume, which induce a pumping action alternately admitting air into and expelling vapor from the tank. Depending on the direction of temperature changes, tank fill, and tank agitation, the vapors may be discharged at any time, with the vehicle either operating or stationary.

In order to distribute the evaporative emissions, it was assumed that these losses occur mainly during the hours 7 a.m.-7 p.m. PDT and that they are evenly distributed over this period. Hence, the evaporative emissions rate from the 4,135,000 automobiles registered in Los Angeles and Orange Counties is 4,135,000 x (72 grams/vehicle/day) or (4,135,000 x 6) grams/hour.

The evaporative emissions in each square are assumed to be proportional to the number of non-freeway vehicle miles in that square. Non-freeway vehicle mileage was chosen as being more representative than any other figure of driving conditions leading to high evaporative emissions, in particular, cars being parked and stop-go driving. The total non-freeway vehicle mileage in the Los Angeles Basin is 72,367,000; thus, the evaporative emissions for square ij are

$$m_{ij} \times \frac{4,135,000}{72,367} \times 6 \times 10^{-3} = 0.343 m_{ij} \text{ kilograms/hour}$$

where m_{ij} = thousands of non-freeway vehicle miles per day driven in square ij, as given in Figure A-3.

References

Hocker, A. J., "Surveillance of Motor Vehicle Emissions in California," Quarterly Progress Report #19, California Air Resources Board (March 1970). *[a]*

Hocker, A. J., "Exhaust Emissions from Privately Owned 1966-1969 California Automobiles: A Statistical Evaluation of Surveillance Data," Supplement to Quarterly Progress Report #19, California Air Resources Board (July 1970). *[b]*

Hurn, R. W., "Air Pollution," (A. Stern, Ed.), Vol. III, Academic Press, 2nd edition (1968).

Larson, G. P., et al., "Distribution and Effects of Automotive Exhaust Gases in Los Angeles," S.A.E. Technical Progress Series, Vol. 6 (1955).

Ozolins, G. and R. Smith, "Rapid Survey Technique for Estimating Community Air Pollution Emissions," Public Health Service Pub. No. 999-AP-29 (1966).

Rehmann, C. R., "Motor Vehicle Exhaust-Emissions--Gary, Indiana," Public Health Service, National Center for Air Pollution Control Publication APTD-68-5 (1968), CFSTI #PB195156.

Rose, A. H., Jr., et al., "Comparison of Auto Exhaust Emissions from Two Major Cities," JAPCA, 15, (August, 1965).

Sigworth, H. W., Bureau of Air Pollution Sciences, Environmental Protection Agency, private communication (May, 1971).

Springer, K. J., "An Investigation of Emissions from Trucks Above 6000 lb-GVW Powered by Spark-Ignited Engines," Final Report Prepared for U.S. Public Health Service, under Contract No. PH 86-67-72, Southwest Research Institute (March, 1969).

State of California Air Resources Board (ARB), "California Exhaust Emissions Standards for Test Procedures for Gasoline-Powered Motor Vehicles," (November 20, 1968).

II. AIRCRAFT EMISSIONS

Aircraft operating from the fifteen airports in the Los Angeles Basin contribute approximately 2% of nitrogen oxides, 4% of organic gases and 3% of carbon monoxide from all sources in the Basin (See Section V). Whereas the contribution of aircraft emissions to the total contaminant load in the Basin is small, the percentages of pollutants in the local environs that are attributable to aircraft operations is quite significant. Furthermore, several of the contaminant monitoring stations are located in the vicinity of airports. Thus, it was necessary to devise a special model to account properly for the local impact of aircraft emissions.

The aircraft emissions model developed for this project consists of two major parts: ground operations and airborne operations. Emissions from these operations are treated as lumped volume sources, generated in the cell into which they are injected. The first part of this section describes the emissions model adopted, and the second part presents relevant data.

A. Aircraft Emissions Model

Aircraft operations are classified as ground operations and airborne operations. *Ground operations* consist of three distinct modes:

(1) Taxi mode

- taxi between runway and satellite upon landing,
- taxi between satellite and end of runway and await clearance for take-off, and
- idle at satellite.

(2) Landing mode

- touchdown on runway to turn-off from runway.

(3) Take-off mode

- start of take-off run to lift-off from runway.

Airborne operations are comprised of two modes:

(1) Approach mode

- descent from inversion height* to touchdown,

(2) Climb-out mode

- lift-off to attainment of inversion height.

A flight, whether for fixed wing aircraft or rotocraft, is defined to consist of the five modes cited.

Several assumptions apply to the treatment of aircraft operations in the emissions model:

(1) For every aircraft arrival, there is one departure. Furthermore, arrival and departure rates are equal within each time period. (Pertinent time periods are shown in Table A-19.)

(2) Aircraft follow straight line flight paths from inversion height to touchdown and from lift-off to inversion height.**

(3) The angles of ascent and descent of all aircraft at a particular airport are assumed to be fixed and equal to those angles associated with the class of craft (e.g., medium range jet transport, business jet, etc.) having the highest fraction of total operations at that facility.***

(4) Flight paths originate and terminate at the most frequently used runway at each airport.

(5) The proportion of aircraft of a given class that arrive and depart from each airport is invariant with time.

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*Inversion height refers to the elevation of the base of the inversion above sea level.

**Many light aircraft never reach inversion height and in fact often do not follow straight line paths above 800 feet. However, information concerning these departures from linear flight paths is not available.

***This assumption is reasonable for twelve of the fifteen Los Angeles Basin Airports, as at these facilities the fraction of total operations assignable to a particular class of aircraft exceeds 0.81. (See Table A-18.) The exceptions are Los Angeles International (LAX), Hollywood/Burbank (LK) and Culver City (CC) Airports. At LAX Class 1 and Class 2 aircraft, transports having similar flight paths, comprise 63% of total daily flights and contribute by far the greatest fraction of contaminants. Class 6 aircraft represent 68% of air traffic at LK, while at CC total daily traffic is very light.

More accurate, but thus far unwarranted, alternative calculations include:

(a) Angles of ascent and descent computed as the weighted sum of the angles assignable to each class of aircraft, weighting being in proportion to the mass emissions of each class.

(b) Computation of individual flight paths for each class.

(6) The temporal distribution of flight operations at a Basin airport, if not known, may be represented by the temporal distribution measured at an airport at which the mix of aircraft, by class, most closely resembles the mix of aircraft at the airport in question.*

It should be noted that emissions along flight paths contained within, but originating from airports lying just outside of, the Basin boundary are ignored (e.g., Ontario International, El Toro Marine Base, etc.)

Turning now to aircraft emissions, we have made the following assumptions:

(1) For each class of aircraft, pollutants are emitted at a uniform rate during each of the five operating modes. Thus, for airborne operations, the amount of contaminants injected into a cell is proportional to the length of the flight path occupying that cell.

(2) Aircraft emissions can be treated as volume sources, well-mixed in the cell into which they are injected. [This is in contrast to the treatment of automobile emissions, which are taken to be fluxes at the ground.]

(3) Emissions from aircraft can be treated as continuous releases, emitted at a uniform rate and averaged over a one-hour time period, one hour being the resolution of the temporal distribution of airport traffic.**

(4) Emissions indices measured for one aircraft are representative of all aircraft of that class.

Ground Operations Model

The amount of contaminant species k emitted into a surface cell during ground operations is equal to the summed products of average emissions rates and residence times in each of three modes--taxi, landing, and take-off. The rate of emissions, in pounds per minute, into any ground cell ijl due to ground operations for the hourly period ℓ is given by:

$$Q^k_{ijm\ell,m=1} = \frac{10^{-3} d_\ell a_{ij}}{K} \sum_{u=1}^{7} n_u M_u \sum_{g=1}^{3} f^k_{gu} C_{gu}$$

*Temporal distributions are available for the following airports: Los Angeles International (Class 1 aircraft predominate), Van Nuys (Class 6) and Hollywood/Burbank (Class 6). Of the remaining twelve airports, ten are predominantly Class 6 (the exceptions being Los Alamitos and Culver City), and the Van Nuys distribution is assumed to be representative of flight operations at these airports.

**This assumption is reasonable when the time step for numerical integration of the overall airshed model is comparatively long (5 to 10 minutes in the case of non-reacting species), but may be questionable in treating photochemical reactions, when shorter time steps are required.

where

i,j are indices for the x,y (horizontal) coordinates,

m is an index for the z (vertical) coordinate and m = 1 for the ground cells,

ℓ is an index representing the hourly period of the day,

k is an index representing individual pollutants

1 CO
2 hydrocarbons
3 NO
4 NO_2

g is an index denoting ground operations modes

1 taxi
2 landing
3 take-off

u is an index denoting aircraft class

1 long-range jet transport
2 medium range jet transport
3 business jet
4 turboprop transport
5 piston engine transport
6 piston engine utility
7 turbine engine helicopter

and

$Q^k_{ijm\ell}$ = emissions rate of species k into cell ijm during time period ℓ (pounds per minute)

d_ℓ = fraction of total daily flights assigned to hourly period ℓ (see Table A-19)

α_{ij} = fraction of airport area assignable to ground cell ijl

K = 60 (minutes/hour)

n_u = number of flights per day of aircraft of class u (see Table A-18).

M_u = average number of engines per aircraft of class u (see Table A-18)

f^k_{gu} = pounds of pollutant k emitted per 1,000 pounds fuel consumed by aircraft of class u operating in mode g (see Table A-14)

C_{gu} = pounds of fuel consumed per engine of aircraft of class u operating in mode g (see Table A-15).

Flight Operations Model

The mass of species k emitted into cell ijm during *approach* is assumed to be proportional to the length of the flight path occupying that cell. The corresponding rate of emissions is given by:

$$Q^k_{ijm\ell} = \frac{10^{-3} d_\ell P_{ijm}}{K} \sum_{u=1}^{7} n_u M_u f^k_u C_u \frac{t_u}{t'_u} \qquad \text{(A-1)}$$

where

t_u = time spent in descent from inversion height to touchdown by aircraft of class u

t'_u = time spent in descent from 3000 feet above ground elevation to touchdown by aircraft of class u (see Table A-16)

f^k_u = pounds of pollutant k emitted by aircraft of class u per 1,000 pounds fuel consumed during descent (see Table A-14)

C_u = pounds of fuel consumed per engine of aircraft of class u during descent from 3000 feet above ground elevation (see Table A-15)

P_{ijm} = fraction of the length of the flight path* assignable to cell ijm**

The mass of species k emitted into cell ijm during *climb-out* is also given by Equation (A-1), where t_u and f^k_u now apply to an aircraft ascending from lift-off to inversion height, and t_u and C_u to an aircraft ascending to 3000 feet above ground elevation.

As all concentration units in the airshed model are expressed as parts per million (ppm), the following conversion formula is used:

$$C^k_{ijm}\left(\frac{ppm}{min}\right) = \frac{10^6 v Q^k_{ijm}}{V_{ijm} W^k}$$

where

Q^k_{ijm} = emissions rate of species k (pounds per minute)

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*The length of the flight path is measured from the base of the inversion to touchdown.

**Cells ijm vary in height from column to column (i.e., over i and j) to account for spatial variations in inversion height at any instant in time. This peculiarity in the definition of cells complicates the calculation of Pijm. The algorithm we have employed for this computation is thus somewhat involved and will not be described here. For full details see the description and listing of the computer program in Appendix F.

W^k = molecular weight of species k

V_{ijm} = volume of cell ijm, cubic feet

v = 379 cubic feet per pound mole, the molal volume of an ideal gas at 1 atmosphere and 60° F.

B. Emissions and Airport Data

As was the case for automobile emissions, the aircraft emissions model has been formulated to utilize available data as effectively as possible. Data may be conveniently classified as information pertaining to (1) aircraft location and (2) aircraft emissions. Included in the former category are airport location and, for each airport, flight paths and runway and taxi-way coordinates. This information is available from U.S. Geological Survey maps, FAA documents and maps, and the administrations of individual airports.

Major aircraft emissions studies have been reported by the Los Angeles County Air Pollution Control District (Lemke, et al. (1965) and George, et al. (1969)), the National Air Pollution Control Administration (Hochheiser and Lozano (1968) and Lozano, et al. (1968)), and Northern Research and Engineering Corporation (Northern Research (1968) and Bastress and Fletcher (1969)). [The three groups will be referred to as LACAPCD, NAPCA, and NREC, respectively]. The NREC study is the most recent and comprehensive of the three, and includes the results of the LACAPCD and NAPCA efforts. For this reason we have relied primarily upon emissions statistics cited in Northern Research (1968).

Pertinent emissions data are given in Tables A-14 and A-15, while airport and aircraft classification and operations data are presented in the remaining tables in this section and in Figure A-7. In particular, classification of aircraft by type (definition of subscript u) is shown in Table A-13. Mass emissions of pollutants per unit of fuel consumed are tabulated in Table A-14 for the various classes of aircraft and operating modes. Fuel consumption rates as a function of aircraft classification and mode of operation are given in Table A-15.

Aircraft performance characteristics for flight operations and take-off and landing are presented in Tables A-16 and A-17. Characteristics include, for each class of craft, the average distance over which the operation is performed, the time required, and, for approach and climb-out, the angles of descent and ascent. The average number of flight operations occurring per day at each of the fifteen Basin airports is tabulated, by class of aircraft, in Table A-18. The distribution of daily operations, by hour, for three major Basin airports is given in Table A-19. Finally, the primary flight paths for each airport are shown in Figure A-7.

Figure A-7 and
Tables A-13 to A-19 follow

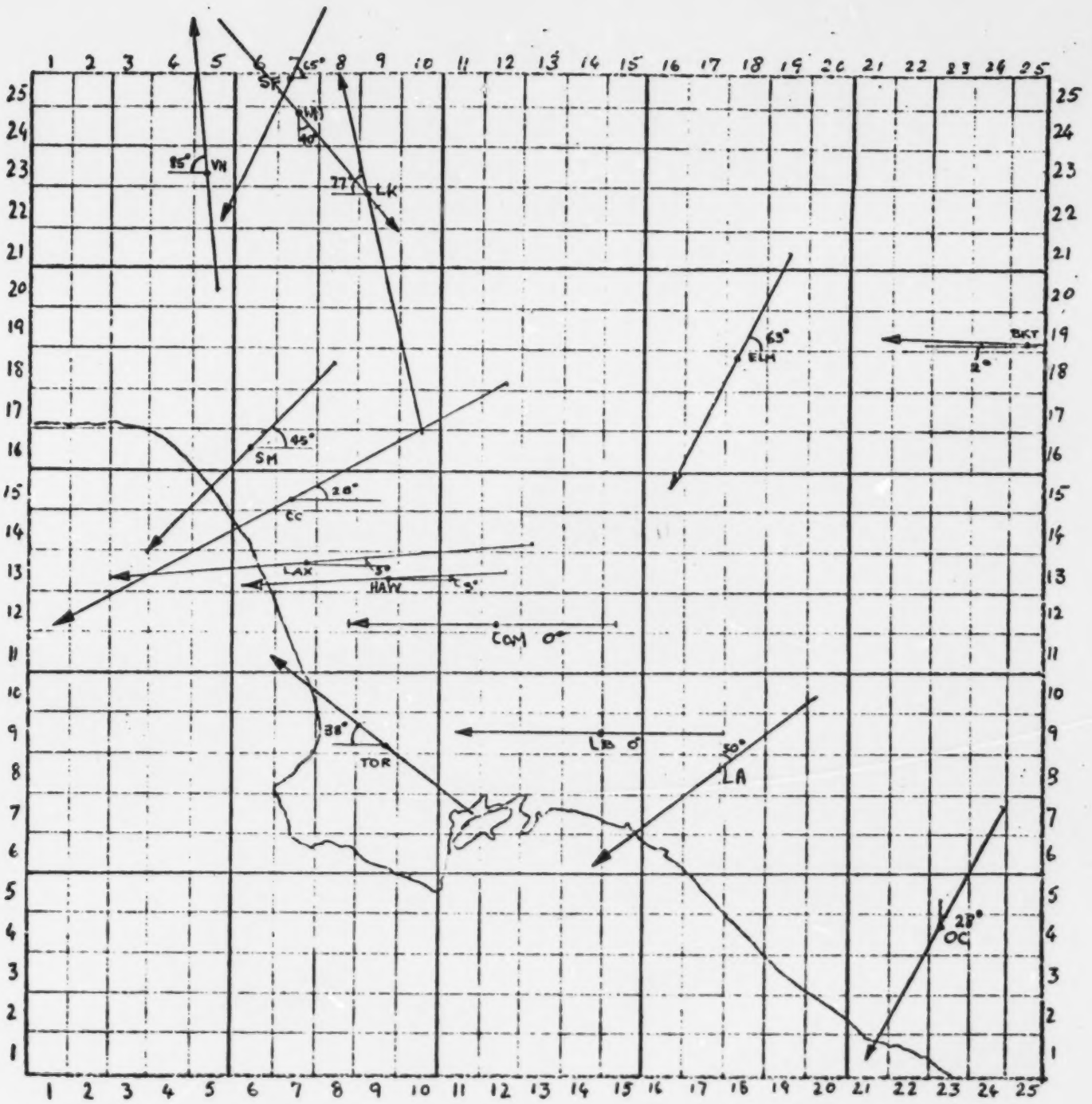
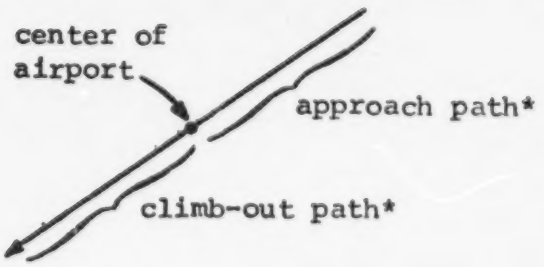


Figure A-7. Approach and Climb-Out Paths for the Fifteen Los Angeles Basin Airports



*Approach and climb-out distances are measured from 3500 feet above runway elevation.

Table A-13. Aircraft Classifications
(Northern Research (1968))

u	Aircraft Type*	Examples	Representative Engine: Manufacturer and Model	Representative Engine: Type
1	Long-range jet transport	Boeing 707 Douglas DC-8	Pratt & Whitney JT3D	Turbofan
2	Medium-range jet transport	Boeing 727 Douglas DC-9	Pratt & Whitney JT8D	Turbofan
3	Business jet	Lockheed Jetstar North American Sabreliner	Pratt & Whitney JT12	Turbojet
4	Turboprop transport	Lockheed Electra Fairchild Hiller FH-227	Allison 501-D13	Turboprop
5	Piston-engine transport	Douglas DC-6 Convair 440	Pratt & Whitney R-2800	Radial piston
6	Piston-engine utility	Cessna 210 Centurion Piper 32-300 Cherokee Six	Continental 10-520-A	Opposed piston
7	Turbine-engine helicopter	Sikorsky S-61 Vertol 107	General Electric CT58	Turboshaft

*The dates chosen for validation of the overall airshed model are September 29 and 30, 1969. An eighth aircraft type, the jumbo jet transport, is not included in this list, as the Boeing 747 was not in service at this time.

Table A-14. Emissions Factors, f_{gu}^k and f_u^k
(Northern Research (1968))

Aircraft Class	Operating Mode	Emission factors, f_{gu}^k and f_u^k (pounds/1000 pounds of fuel) CO	Organics	NO_x
u = 1	Idle & Taxi	174	75	2.0
	Approach	8.7	16	2.7
	LTC*	0.7	0.1	4.3
2	Idle & Taxi	50	9.6	2.0
	Approach	6.6	1.4	2.7
	LTC	1.2	0.6	4.3
3	Idle & Taxi	118	11.5	2.0
	Approach	11	0.6	2.7
	LTC	4	0.3	4.3
4	Idle & Taxi	24.8	8.1	3.7
	Approach	1.6	0	2.9
	LTC	2.3	3.2	3.1
5	Idle	600	160	0
	Taxi	900	90	3
	Approach	800	60	5
	LTC	1250	190	0
6	Idle	600	160	0
	Taxi	900	90	3
	Approach	800	60	5
	LTC	1050	110	1
7	Idle & Taxi	118	11.5	2.0
	Approach	11	0.6	2.7
	Climb-out	4	0.3	4.3

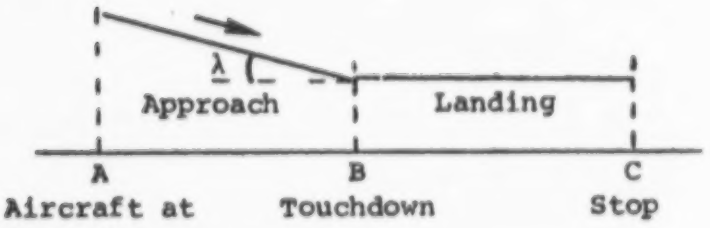
*Land, Take-Off and Climb-Out

Table A-15. Fuel Consumption During Landing and Take-Off Operations for Representative Engines (Northern Research (1968))

Aircraft Class	Representative Engine	Fuel Consumed, C_{gu} and C_u (pounds per engine)						
		Taxi	Idle	Landing Run	Take-Off Run	Approach*	Climb-Out*	Total LTO-Cycle
u = 1	Pratt & Whitney JT3D	217.4	18.1	36.4	158.5	298.2	279.0	1007.6
2	Pratt & Whitney JT8D	184.0	15.3	16.1	103.5	141.3	196.7	656.9
3	Pratt & Whitney JT12	108.0	9.0	12.9	22.3	47.1	22.3	221.7
4	Allison 501-D13	118.8	8.5	4.9	20.4	66.9	97.8	317.4
5	Pratt & Whitney R-2800	72.0	2.7	5.3	21.0	36.8	140.0	277.8
6	Continental IO-520-A	5.6	0.4	0.1	0.9	2.7	4.7	14.4
7	General Electric CT58	37.0	3.0	0.0	0.0	59.4	77.0	176.4

*Between ground elevation and 3000 feet.

Table A-16. Aircraft Performance Characteristics During Approach and Landing Operations (Northern Research (1968))



S_{AB} Distance A to B S_{BC} Distance B to C

$t_u' = t_{AB}$ Time to Travel A to B t_{BC} Time to Travel B to C

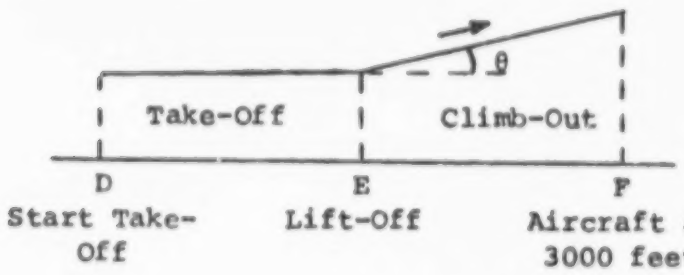
λ Angle of Descent

Aircraft Class	S_{AB} (Miles)	t_{AB} (Minutes)	S_{BC} (Feet)	t_{BC} (Minutes)	λ (Degrees)
u = 1	9.4	3.6	2800	0.4	3.46
2	9.0	3.0	1900	0.3	3.61
3	6.0	1.6	1900	0.4	5.41
4	10.3	4.5	1700	0.3	3.16
5	9.0	4.6	2330	0.6	3.61
6	5.0	3.8	1000	0.3	6.48
7	15.0	6.5	0	0	2.17

Durations of idle and taxi modes are assumed to be 1 and 12 minutes respectively for classes 1 through 6, and 1 and 6 minutes for class 7 (helicopters).

*Above ground elevation.

Table A-17. Aircraft Performance Characteristics During Take-Off and Climb-Out Operations
(Northern Research (1968))



S_{DE} Distance D to E S_{EF} Distance E to F

t_{DE} Time to Travel D to E $t'_u = t_{EF}$ Time to Travel E to F

θ Angle of Ascent

Aircraft Class	S_{DE} (Feet)	t_{DE} (Minutes)	S_{EF} (Miles)	t_{EF} (Minutes)	θ (Degrees)
u = 1	9300	1.0	8.1	2.2	4.01
2	6075	0.8	6.5	1.9	5.00
3	2800	0.4	4.0	0.5	8.08
4	3280	0.6	10.6	3.6	3.07
5	3150	0.6	14.8	5.0	2.20
6	1545	0.4	6.3	2.5	5.15
7	0	0	15.0	6.5	2.17

Table A-18. Average Number of Aircraft Flights Per Day at Los Angeles Basin Airports[1,2]

Airport \ Aircraft Class	1	2	3	4	5	6	7
Brackett	0	0	6(1.5)	0	0	288(1.0)	10(1.0)
Compton	0	0	0	0	0	191(1.0)	0
Culver City	0	0	12[5](1.0)	0	0	21(1.9)	20(1.0)
El Monte	0	0	0	0	0	700(1.0)	0
Hawthorne	0	0	0	0	0	428(1.0)	0
Hollywood/Burbank	0	47(2.5)	19(2.0)	4(2.8)	25(4.0)	225(1.6)	10(1.0)
Long Beach	0	0	2(2.0)	0	67(4.0)	591(1.4)[3]	25(1.0)
Los Alamitos[4]	0	0	300[5](1.0)	0	50(2.0)	0	0
Los Angeles Int'l.	331(4.0)	196(2.9)	9(1.0)	57(2.9)	21(3.2)	159(1.4)[3]	58(2.0)
Orange County	0	12(2.0)	0	0	0	850(1.4)[3]	0
San Fernando	0	0	0	0	0	100(1.1)	0
Santa Monica	0	0	3(2.0)	0	0	525(1.1)	25(1.0)
Torrance	0	0	0	0	0	500(1.1)	0
Van Nuys	0	0	25(2.0)	0	14(4.0)	720(1.0)	125(1.0)
Whiteman	0	0	0	0	0	200(1.1)	0

[1]1968 data.

[2]Numbers in parentheses are average numbers of engine per aircraft.

[3]Total national average--FAA controlled terminals (Northern Research (1968)).

[4]Airport closed March 1, 1971.

[5]Class 3 activity at this terminal is mostly military aircraft. Military engines are estimated to be equivalent to six Class 3 aircraft engines. Thus, numbers of flights shown are actual flights multiplied by six.

Table A-19. Temporal Distributions of Daily Flights at Three Los Angeles Basin Airports

Time Period*	Fraction of Daily Traffic
Los Angeles International**	
11 p.m.-1 a.m.	.048
1-7	.051
7-8	.043
8 a.m.-6 p.m.	.629
6-8	.109
8-9	.048
9-11	.072
Van Nuys***	
10 p.m.-8 a.m.	.017
8-9	.014
9-10	.056
10-12 noon	.156
12-4	.511
4-5	.078
5-7	.103
7-8	.036
8-9	.021
9-10	.008
Hollywood/Burbank***	
11 p.m.-1 a.m.	.026
1-7	.021
7-9	.063
9-12 noon	.193
12-1	.087
1-4	.164
4-8	.314
8-9	.062
9-11	.070

*Distributions are approximately uniform within each time period.

**Derived from hourly distributions for the period June 1, 1970 through June 30, 1970.

***Derived from hourly distributions at an unspecified weekday in 1970.

References

Bastress, E. K. and R. S. Fletcher, "Aircraft Engine Exhaust Emissions," presented at American Society of Mechanical Engineers Annual Winter Meeting, Los Angeles (November 16-20, 1969).

George, R. E., J. A. Verssen, R. L. Chass, "Jet Aircraft--A Growing Pollution Source," presented at 62nd Annual Meeting of APCA, paper 69-191 (June 1969).

Hochheiser, S. and E. R. Lozano, "Air Pollution Emissions from Jet Aircraft Operating in the New York Metropolitan Area," presented at Air Transportation Meeting, New York (April 29-May 2, 1968).

Lemke, E. E., N. R. Shaffer, and J. A. Verssen, "Air Pollution From Aircraft in Los Angeles County," report of the Los Angeles County Air Pollution Control District (December 1965).

Lozano, E. R., W. W. Melvin, Jr., S. Hochheiser, "Air Pollution Emissions From Jet Engines," JAPCA, 18 (June 1968) p. 392-394.

Northern Research and Engineering Corporation, "Nature and Control of Aircraft Engine Exhaust Emissions," (November 1968) CFSTI #PB 187771.

III. FIXED SOURCE EMISSIONS--POWER PLANTS AND REFINERIES

The eleven power plants situated in the Los Angeles Basin emit approximately 17 % of NO_x from all Basin sources. The fifteen oil refineries contribute an additional 9 % of NO_x and 7 % of organic gas emissions (see Section V). Although emissions from these large point sources can result in elevated ground concentrations in their immediate vicinity, we have chosen not to incorporate calculations in the present grid model to account for this effect. However, because of the high emissions rates from these sources, and their special emission characteristics, it is unrealistic to treat them simply as area sources. In the first two parts of this Section, we describe the methods of incorporating the emissions into the overall grid model and summarize pertinent data relating to power plants and refineries. Finally, in the third part, we describe in detail a method for estimating concentrations resulting from large point sources. We then make suggestions for possible methods of estimating concentrations for reacting gases and unsteady conditions.

A. Power Plant Model

High emissions rates from point sources can result in high local ground concentrations. For power plants of the size found in the

Los Angeles Basin and under typical meteorological conditions, maximum ground concentrations occur at distances from the plant of the order of two miles. If the power plants were treated simply as area sources, it would not be possible to predict these high concentrations and the locations of their occurrence using a grid of two-mile resolution. On the other hand, one can argue that a more detailed treatment of plumes (such as the use of established plume dispersion models) may not be warranted, given the expected accuracy of prediction associated with a two-mile grid. However, such a treatment of plumes may in fact be necessary in model validation when the air quality data with which predictions are to be compared are collected at monitoring stations in the immediate vicinity of a power plant.

If power plants are to be treated as point sources, it is necessary to perform a plume calculation *in addition* to the calculation of concentrations through numerical integration of the continuity equations. Ground level concentrations of non-reacting contaminants at a point are computed by adding concentrations due to power plant emissions to concentrations at that point resulting from contaminant emissions from other sources. Before adopting this procedure, however, it seemed wise to determine if it was required for validation of September 29 and 30 data.

Of the sixteen contaminant monitoring stations in the Basin, only those at Redondo Beach (RB), Burbank (BURK), and Pasadena (PASA) are located within five miles of power plants. RB measures SO_2 alone. The power station at Burbank is located a mere 100 to 200 meters from BURK; BURK thus receives virtually no NO_x from that source under normal daytime conditions. (Early morning fumigation will give rise to high concentrations at BURK. No attempt was made to model this phenomenon in the current study.) Only PASA, about 2,000 meters ENE of the Pasadena power station, is likely to detect elevated NO_x emissions. The data of September 29 and 30, 1969, however, do not confirm this hypothesis. NO_x levels at PASA follow the pattern observed at other stations, and in fact are quite low during the day. Since none of the air quality measurements used for validation were likely to be influenced by the presence of power plants, we chose not to include plume dispersion calculations in the model for the current validation studies. However, we *have* proposed a simple method for handling these calculations, should they be required in future validation programs and in the exercise of the model. This procedure, applicable to steady-state, non-reacting plumes, is described in some detail in Part C.

While power plant and refinery emissions are not treated as plumes in the model, it was believed inappropriate simply to consider power plant emissions as well mixed in the cell into which they are injected. Instead, these emissions are distributed as volume sources downwind of the plant, in cells where the plume width has grown to be of the order of the cell size. This procedure is outlined in the first section of this Part. In the second section we present all pertinent data relating to power plants and their emissions. In contrast, refinery emissions are treated as area sources and are discussed in Part B.

1. Treatment of point-source emissions as volume sources

A Gaussian dispersion model was used to evaluate the possibility of treating point source emissions as volume sources centered in grid squares downwind of the square in which the point source is located. Pollutant concentrations are assumed to be normally distributed in the horizontal and vertical planes with dispersion parameters, σ_y and σ_z, respectively. (For a description of the plume dispersion model, see Part C, section 1.) The half-width, b, of the plume is defined as $2.15\sigma_y$ and is the horizontal distance from the plume center-line to the point at which the concentration is 10% of its center-line value. (See Figure A-17.) The parameters σ_y and σ_z are functions both of downwind distance and of atmospheric stability. Correlations of σ_y and σ_z with these variables are shown in Figures A-8 and A-9, the different stability classes being defined in Table A-20.

Having defined the half-width, b, we can now estimate plume spread as a function of downwind distance using the plume dispersion model. The result of this calculation, shown in Figure A-10, indicates that the plume width for stability class B (the most prevalent during daytime hours) is about two miles at 3.75 miles downwind. It is therefore reasonable to treat emissions as volume sources in adjacent 2x2 mile grid squares downwind of the plant. Furthermore, the values of σ_z shown in Figure A-9 suggest that at this distance the plume is well mixed up to the inversion base (assumed to be located at a maximum elevation of 3,000 feet). The volume sources are therefore distributed evenly in the column of cells up to the inversion base.

Emissions from a point source of strength V (pounds/hour) located in the ground cell (ijl) are distributed in the following manner. (See Figure A-11.) A straight line is drawn starting at the source location parallel to and in the direction of the wind in that square. This line extends to the farthest edge of that square either touching or immediately diagonal to the square containing the source. The emissions from the point source are then apportioned as volume sources in the two or three columns of cells through which this line passes. The strength of the volume source in each cell is proportional to the length of the line contained in that cell, with the sum of the volume sources being equal to the strength of the point source. For example, referring to the situation shown in Figure A-11, the volume source strength allocated to the column of cells whose base is square i+1,j is equal to $V \times r_2/(r_1 + r_2 + r_3)$.

2. Emissions and other relevant data

Of the eleven power plants in the Los Angeles Basin, four are operated by the Southern California Edison Company, four by the Los Angeles Department of Water and Power, and one each by the cities of Pasadena, Burbank and Glendale. Data relating to plant locations and electric capacities are given in Table A-21 and Figure A-12. Finally, emissions data for each plant are shown in Table A-22. These data were obtained from the authorities cited:

Figures A-8 to A-12
and Tables A-20 to A-22 follow

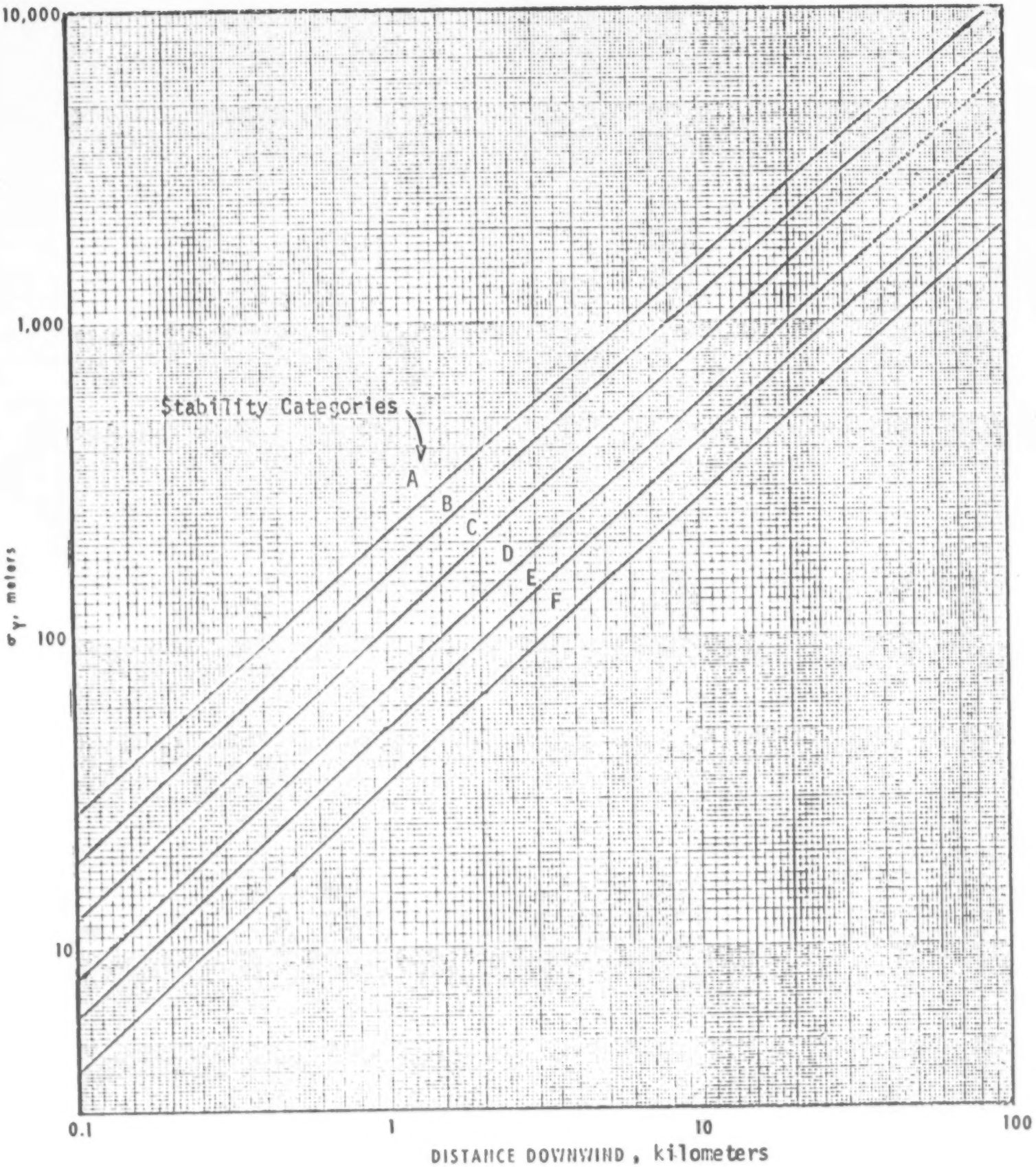


Figure A-8. Horizontal Dispersion Coefficient as a Function of Downwind Distance From the Source (Turner (1969))

(See Table A-20 for key to stability categories.)

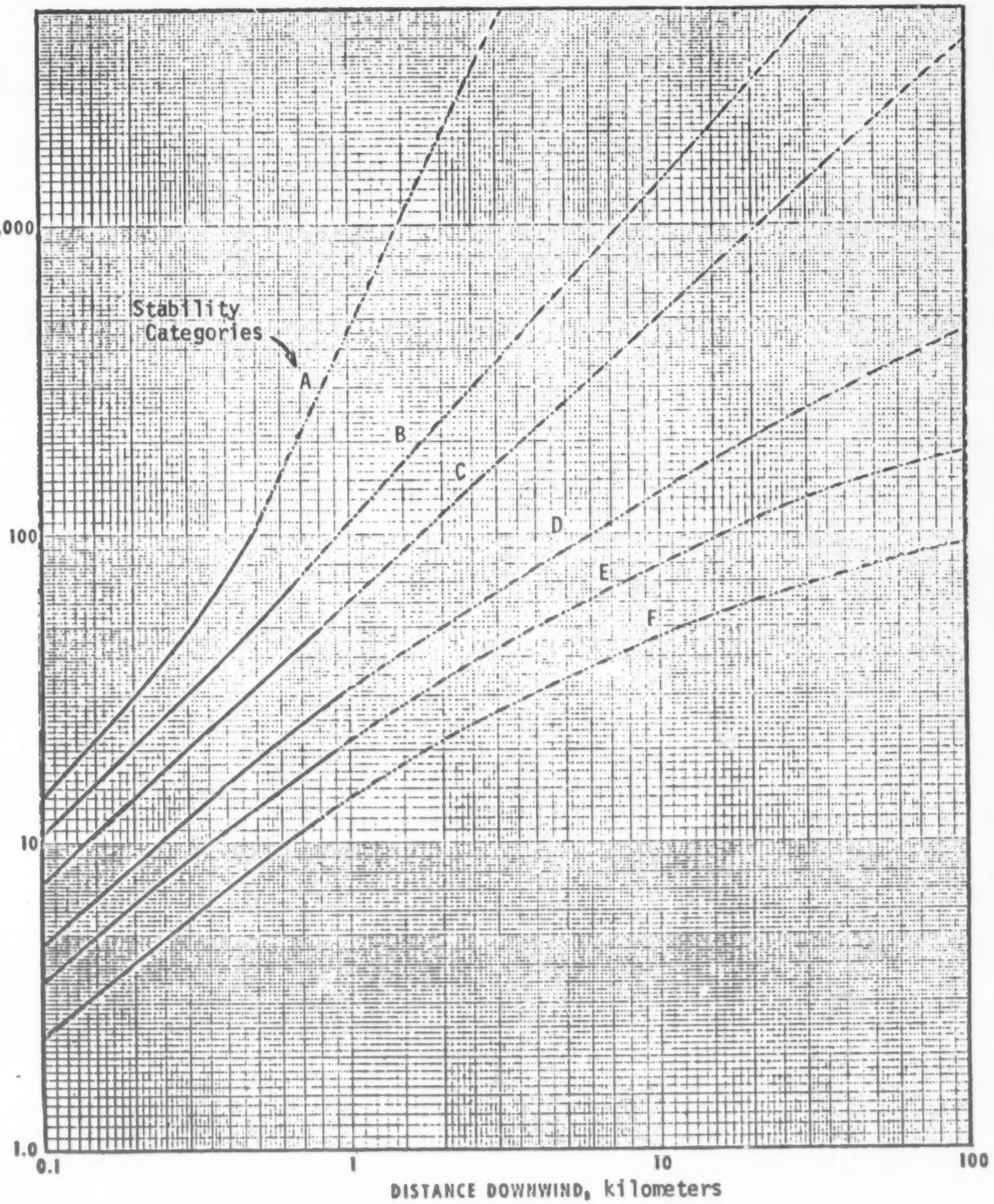


Figure A-9. Vertical Dispersion Coefficient as a Function of Downwind Distance From the Source (Turner (1969))

(See Table A-20 for key to stability categories.)

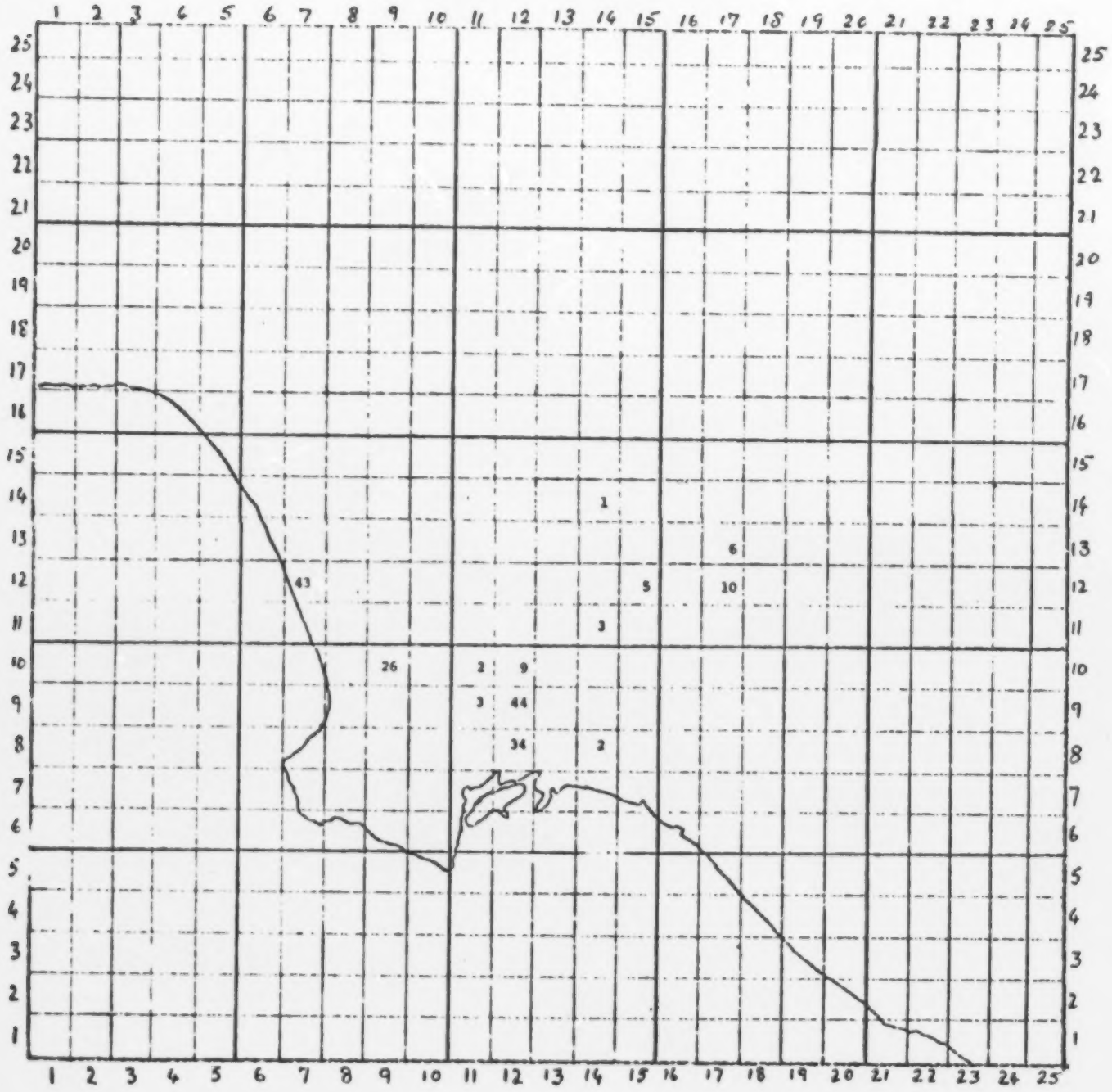


Figure A-15. High Reactivity Organic Gas Emissions (kilograms/hour) From Oil Refineries

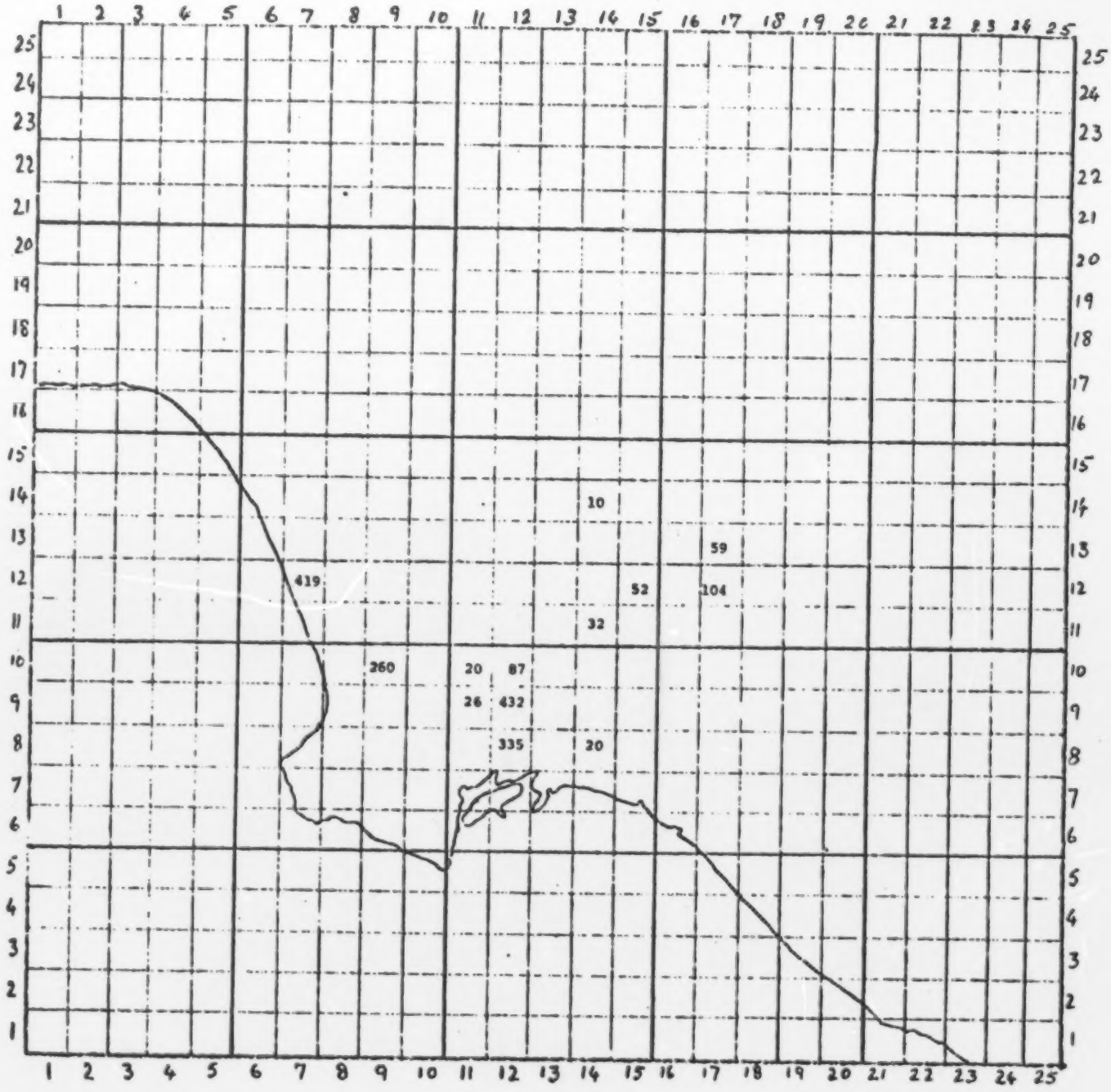


Figure A-16. Low Reactivity Organic Gas Emissions (kilograms/hour) From Oil Refineries

Table A-23. Locations and Capacities of Los Angeles Basin Refineries

Refinery Number†	Name	Refinery Location (Square Number†)	Coordinates* of Refinery Location (miles)	Crude Capacity** (barrels/stream day)
1	Atlantic Richfield Co.	12,9††	1.2,0.3	173,000
2	Douglas Oil Co. of California	15,12	0.2,0.9	26,000
3	Edgington Oil Refineries, Inc.	14,11	1.3,0.9	16,000
4	Fletcher Oil & Refining Co.	11,9	0.6,1.2	13,000
5	Carson Oil Co., Inc.	10,10	0.3,0.8	10,000
6	Gulf Oil Corporation	17,12	1.7,1.7	51,000
7	Lunday-Thagard Oil Co.	14,14	1.1,0.5	3,000
8	MacMillan Ring-Free Oil Co.	14,8	1.0,1.4	10,000
9	Mobil Oil Corporation	9,10	1.1,1.7	130,000
10	Powerine Oil Co.	17,13	0.7,1.3	30,000
11	Shell Oil Company	12,10	0.9,1.0	44,000
12	Shell Oil Company	12,9	0.6,0.8	44,000
13	Standard Oil of California	7,12	1.0,1.6	210,000
14	Texaco, Inc.	12,8	1.1,1.3	61,000
15	Union Oil Co. of California	12,8	0.7,0.6	107,000

*Horizontal and vertical distances, respectively, measured to the approximate center of the area covered by the refinery from the lower left-hand corner of the square containing the refinery.
**Oil and Gas Journal, April 6, 1970.

†See Figure A-13 for refinery locations.

††Horizontal and vertical coordinates, respectively, with the origin at the southwest corner of the 50x50 mile area under consideration. (See Figure A-13.)

C. Alternate Models for Large Point Sources

In this section we consider procedures for estimating contaminant concentrations due to large point sources. Existing procedures provide only crude estimates of ground concentrations owing to the difficulty in describing mathematically the complexities of plume phenomena--chemical reactions in the plume, unsteady emissions rates, varying meteorological conditions, uncertainty of plume trajectories, and the difficulty of accurately determining atmospheric dispersion coefficients. In the first part of this section, we describe in some detail a method of estimating concentrations applicable to steady-state, non-reacting plumes. The second part contains suggestions for more advanced treatments, useful for unsteady conditions and for reacting plumes.

1. Estimation of local concentrations for steady-state, non-reacting plumes

The problem of modeling a steady-state, non-reacting plume which results from a point source consists of two parts:

(1) Estimation of the height at which the buoyant plume becomes essentially horizontal (plume rise).

(2) Estimation of the concentration distribution in the plume.

In order to estimate plume rise, it is necessary to choose a suitable formula from the many suggested for this purpose. The "best" formula is probably one derived from tests on stacks having geometries, and operated under conditions, similar to those being considered. It is also desirable that the tests be made under meteorological conditions resembling those of the locale of interest. Reference should be made to the literature on the subject for guidance in making a choice; particularly useful are the review articles of Briggs (1969) and Strom (1968). Estimates of contaminant levels in a dispersing plume are usually based on the assumption of a normal concentration distribution. Turner (1968) and Strom (1968) discuss this and other formulations that have been proposed. In this section we first suggest a useful plume rise formula and then outline a method of estimating contaminant levels for various inversion conditions, based on the assumption of a normal concentration distribution.*

---

*The origin of the coordinate system to which we will refer is at ground level, at or beneath the point of emission, with the x-axis extending horizontally in the direction of the mean wind. The y-axis is in the horizontal plane perpendicular to the x-axis, and the z-axis extends vertically. The plume travels along or parallel to the x-axis. Figure A-17 illustrates the coordinate system.

Figure A-17 follows

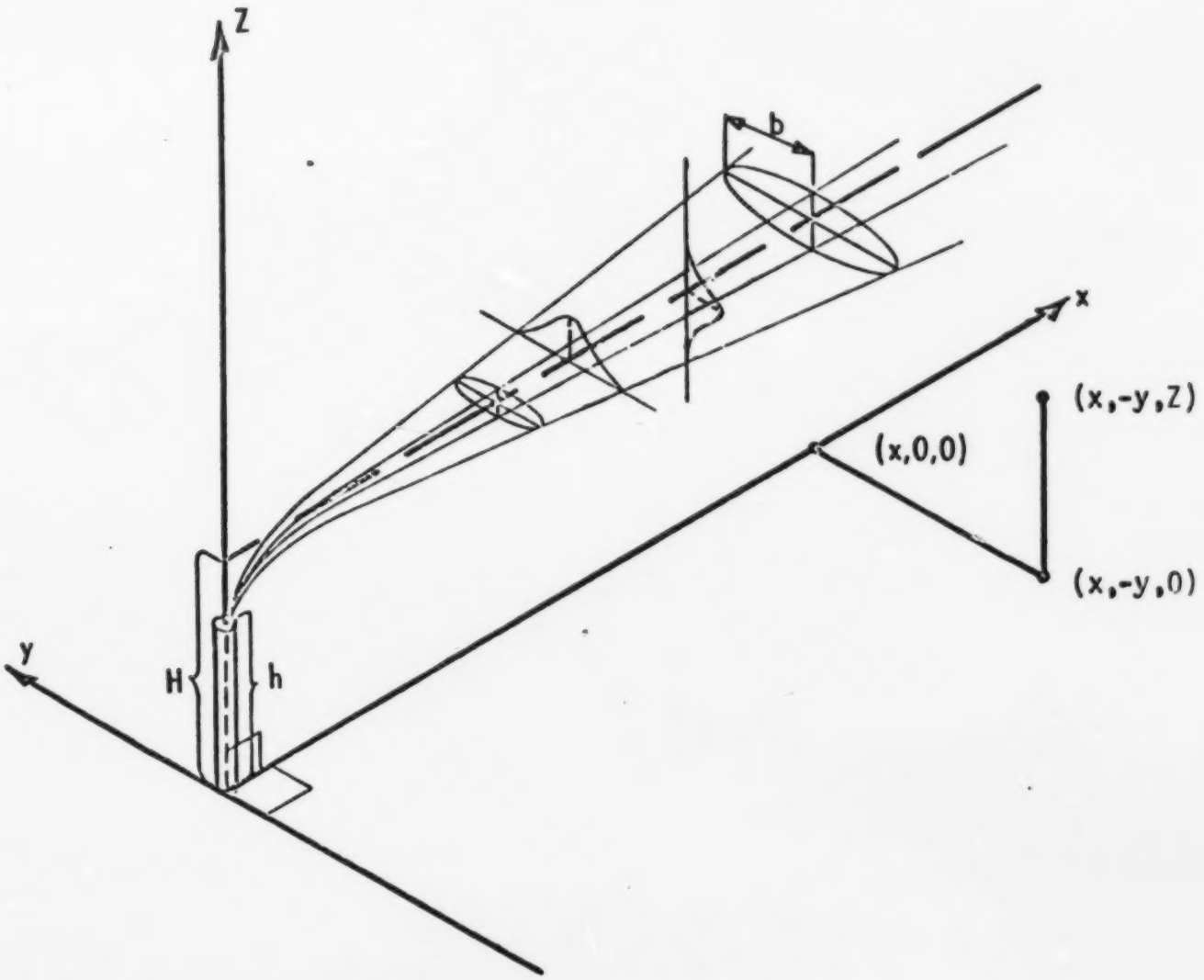


Figure A-17. Coordinate System Showing Gaussian Distributions in the Horizontal and Vertical and Plume Half-Width

Plume Rise

An equation that might be used to describe plume rise from power plants of the type found in the Los Angeles Basin is due to Holland (1953):

$$\Delta H = \frac{V_s d}{U}(1.5 + 2.68 \times 10^{-3} p \frac{T_s - T_a}{T_s} d) \qquad \text{(A-2)}$$

(for neutral atmospheric stability)

where

ΔH = the rise of the plume above the stack, meters

V_s = stack gas exit velocity, meters/second

d = the inside stack diameter, meters

u = wind speed, meters/second

p = atmospheric pressure, millibars

T_s = stack gas temperature, °K

T_a = air temperature, °K

To account for atmospheric conditions other than neutral, Holland suggests multiplying the value of ΔH calculated from Equation (A-2) by a, where:

$1.1 < a < 1.2$ for unstable conditions;

$0.8 < a < 0.9$ for stable conditions.

This empirical equation was derived from experimental observations made at the Oak Ridge and the Watts Bar steam plants in Tennessee. These stacks are similar to those found in the Los Angeles Basin (stack diameters from 1.7 to 4.3 meters and exit temperatures from 82 to 204°C). The tests, however, were conducted in a rural area and under atmospheric stability conditions dissimilar to those common to Los Angeles. It should also be noted that Holland's equation was based on photographic data that followed the plumes only 600 feet downwind. If this equation is extrapolated to downwind distances of the order of a few miles, appreciable errors may result.

Plume Dispersion

The steady state contaminant concentration, ψ, at any point x, y, z, resulting from a continuous source with an effective emission height H,* is given by:

*H is the sum of stack height, h, and plume rise, ΔH.

$$\psi(x,y,z) = \frac{V}{2\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]\right.$$

$$\left. + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \qquad \text{(A-3)}$$

This relationship was developed with the following assumptions (see Turner (1969)):

- the plume concentration is normally distributed in the horizontal and vertical planes, with standard deviations σ_y and σ_z respectively;
- the mean wind speed affecting the plume is u;
- the uniform emissions rate of pollutants is V; and
- total reflection of the plume takes place at the earth's surface.

To estimate concentrations when an inversion is present, the following procedures are recommended:

(1) *Effective emission height less than inversion height (Turner 1969)*

Allow σ_z to increase with distance downwind until it becomes equal to 0.47 (L - H), where L is the height of the inversion base. At this distance, x_L, the plume is assumed to have a Gaussian distribution in the vertical. Assume that by the time the plume travels twice this far, $2x_L$, the plume is uniformly distributed between the earth's surface and the inversion height, L. Thus:

- For $x < x_L$ (but greater than a few hundred meters), Equation (A-3) is applicable.
- For $x > 2x_L$,

$$\psi(x,y,z) = \frac{V}{\sqrt{2\pi}\ \sigma_y L u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

- For $x_L < x < 2x_L$, the best approximation of the concentration is that read from a straight line drawn between the calculated concentrations at points x_L and $2x_L$ on a log-log plot of concentration as a function of distance.

(2) *Effective emission height greater than inversion height*

This situation is discussed by Roberts, et al. (1970), who made the following assumptions:

(a) If the physical stack height h is greater than L, an infinite value for L is assumed, with plume rise and dispersion estimated for stable atmospheric conditions.

(b) If the stack height h is less than L, a minimum plume rise ΔH_{min} is calculated, based on the coefficients for stably stratified air.

- If the minimum effective emission height, $H = h + \Delta H_{min}$, is greater than the lid height L, H is used as the effective emission height. The plume is then analyzed as described in (a).

- If $(h + \Delta H_{min}) < L$ and if the plume rise ΔH based on the actual stability class yields an effective emission height greater than L, i.e., if $(h + \Delta H_{min} < L)$ and $(h + \Delta H \geq L)$, the effective emission height is restricted to the lid height L.

When the method outlined in this section for estimating ground level concentrations is used, it is also necessary to incorporate point source emissions into the overall grid model. This can be done by treating the emissions as volume sources located either in cells downwind of the point for which the concentration calculation was performed, or in cells containing and adjacent to the point source. However, one should exercise care to ensure that emissions are not doubly counted and that ground level concentrations are not artifically elevated in cells where the volume sources have been located.

2. Further suggestions for the treatment of large point sources

A better estimate of concentrations resulting from non-reacting plumes, especially under unsteady conditions, can be obtained by use of the so-called "puff" model.* This model is based on the assumption of a Gaussian concentration distribution. However, in contrast to the plume model, this distribution is assumed for all three spatial coordinates, as applied to an instantaneously released, expanding puff. As each incident of release may be treated as a separate event, the assumption of steady

*That estimates of ground level concentrations obtained from the puff model are superior to those calculated from plume models has not been conclusively established. However, Roberts, et al. (1970) report that predictations based on a puff model (Roberts, et al. (1969)) compare more favorably with the Chicago data for which they were validated than do plume predictions (Turner (1968)) for a St. Louis data base. See Roberts et al. (1970), p. 17, for further details.

state is unnecessary, and variations in wind speed, wind direction, emissions rate, and inversion height with time may be accommodated in a straightforward (although somewhat involved) manner. The possibility also exists that this method of analysis may be extended to account for simple chemical reactions. A description of the puff model, along with further references, can be found in Roberts, et al. (1970).

It is not well understood how to model a reacting plume. A possible method of attack might begin with the estimation of the boundaries of the plume using the Gaussian dispersion equation. As the plume quickly comes to rest relative to the surrounding air (the plume has no horizontal momentum), this boundary can be considered a surface in three-dimensional space. The volume contained by this surface may then be divided into cells by passing planes perpendicular to the plume axis. Each cell is assumed to be a well-stirred tank, with transport by convection at the prevailing wind velocity across the cell interfaces. By applying a reaction scheme to this cell model, the concentrations of any species may be predicted as a function of time. When a linear dimension of a cell has grown so as to be comparable to the grid size, the contents of that cell are injected as a flux into the grid square. Thereafter, point-source emissions are accounted for by integration of the continuity equations on which the airshed model is based.

References

Briggs, G. A., "Plume Rise," AEC Critical Review Series (November 1969) CFSTI No. TID-25075.

Holland, J. Z., "A Meteorological Survey of the Oak Ridge Area," Atomic Energy Commission, Report ORO-99, Washington, D.C. (1953).

List, R. J., "Smithsonian Meteorological Tables," 6th Revised Ed., Washington, D.C., Smithsonian Institution (1951).

Roberts, J. J., et al., "An Urban Atmospheric Dispersion Model," Proc. Symp. Multiple Source Urban Diffusion Models, Chapel Hill, N.C. (October 1969) (in press).

Roberts, J. J., et al., "A Multiple Source Urban Atmospheric Dispersion Model," Argonne National Laboratory, ANL/ES--CC007 (May 1970).

Strom, G. H., "Atmospheric Dispersion of Stack Effluents," in Air Pollution," (A. Stern, Ed.) Vol. I, Academic Press (1968).

Turner, D. B., "Relationships Between 24-Hour Mean Air Quality Measurements and Meteorological Factors in Nashville, Tennessee," JAPCA, 11, pp. 483-489 (1961).

Turner, D. B., "Workbook of Atmospheric Dispersion Estimates," U.S. Department of Health, Education and Welfare, Public Health Service, Pub. No. 999-AP-26 (1969).

IV. FIXED SOURCE EMISSIONS--DISTRIBUTED SOURCES

Distributed fixed sources (defined as all fixed sources, with the exception of power plants and oil refineries) account for approximately 10% of NO_x and 26% of organic gas emissions from all sources in the Los Angeles Basin. (See Section V.) These sources will be treated uniformly as area sources, assignable to a grid node. In this Section we describe the method of distributing each source in space and time.

Some of the emissions from distributed fixed sources are spread over highly populated areas, and for this reason it was necessary to divide the modeling area into regions of high and low population density. The areas of low population density are shown in Figure A-18, and the total number of squares in each category are tabulated in Table A-24.

The emissions figures contained in this Section are obtained from:

(1) "Profile of Air Pollution Control in Los Angeles County," Los Angeles County Air Pollution Control District, January 1969, hereafter referred to as "LACAPCD."

(2) "Emissions Inventory--1969," County of Orange Air Pollution Control District, August 1970.

A. Oxides of Nitrogen

1. Los Angeles County

Petroleum marketing, domestic, ship and railroad emissions contribute 46 tons/day.

In order to distribute nitrogen oxide emissions, the following assumptions were made:

(1) Half of the total daily domestic* emissions (17.5 tons) occur between 6 a.m. and 6 p.m. PST.

(2) The total daily emissions attributable to petroleum marketing operations (10 tons) occur between 6 a.m. and 6 p.m. PST.

(3) Half of the daily ship and railroad emissions (1/2 ton) occur at the Port of Los Angeles.

(4) The emissions cited in (1) and (2) above, plus an additional 1/2 ton due to ships and railroads (i.e., a total of 28 tons), are distributed uniformly over the 262 high-population squares of Los Angeles County.

(5) All emissions rates, whether assignable to a twelve or twenty-four hour period, are uniform between 6 a.m. and 6 p.m. PST.

*Domestic, commercial and industrial facilities on firm natural gas schedules.

Figure A-18 and Table A-24 follow

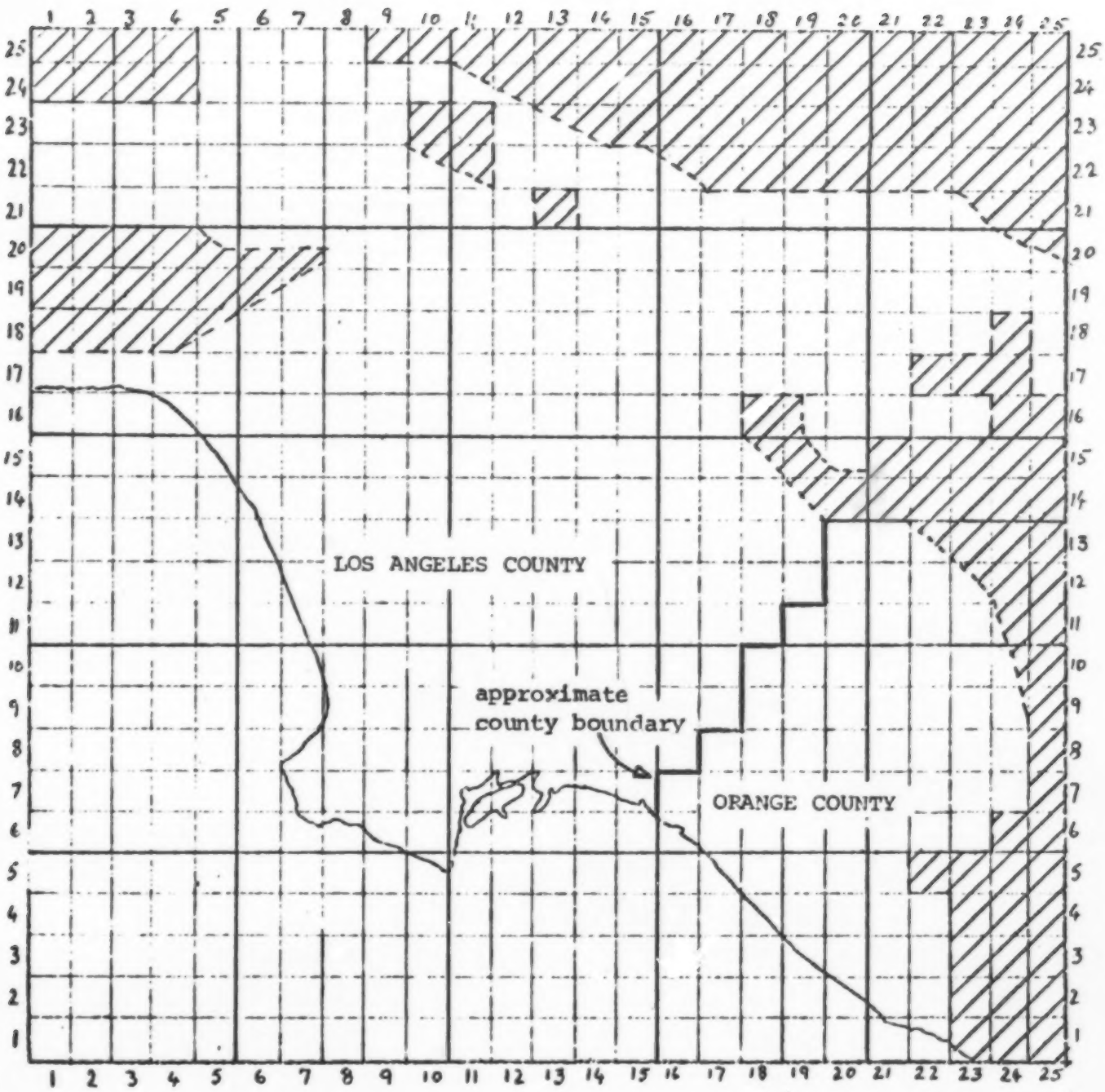


Figure A-18. Population Density Distribution of the Los Angeles Basin

(Areas of low population density are cross-hatched.)

Table A-24. Grid Square Classification
by Population Density

	Population Density	Number of Squares	
Los Angeles County			
	High	262	
	Low	101	
	Total		363
Orange County			
	High	68	
	Low	28	
	Total		96
Total over land			459
Total over ocean			166
	TOTAL		625

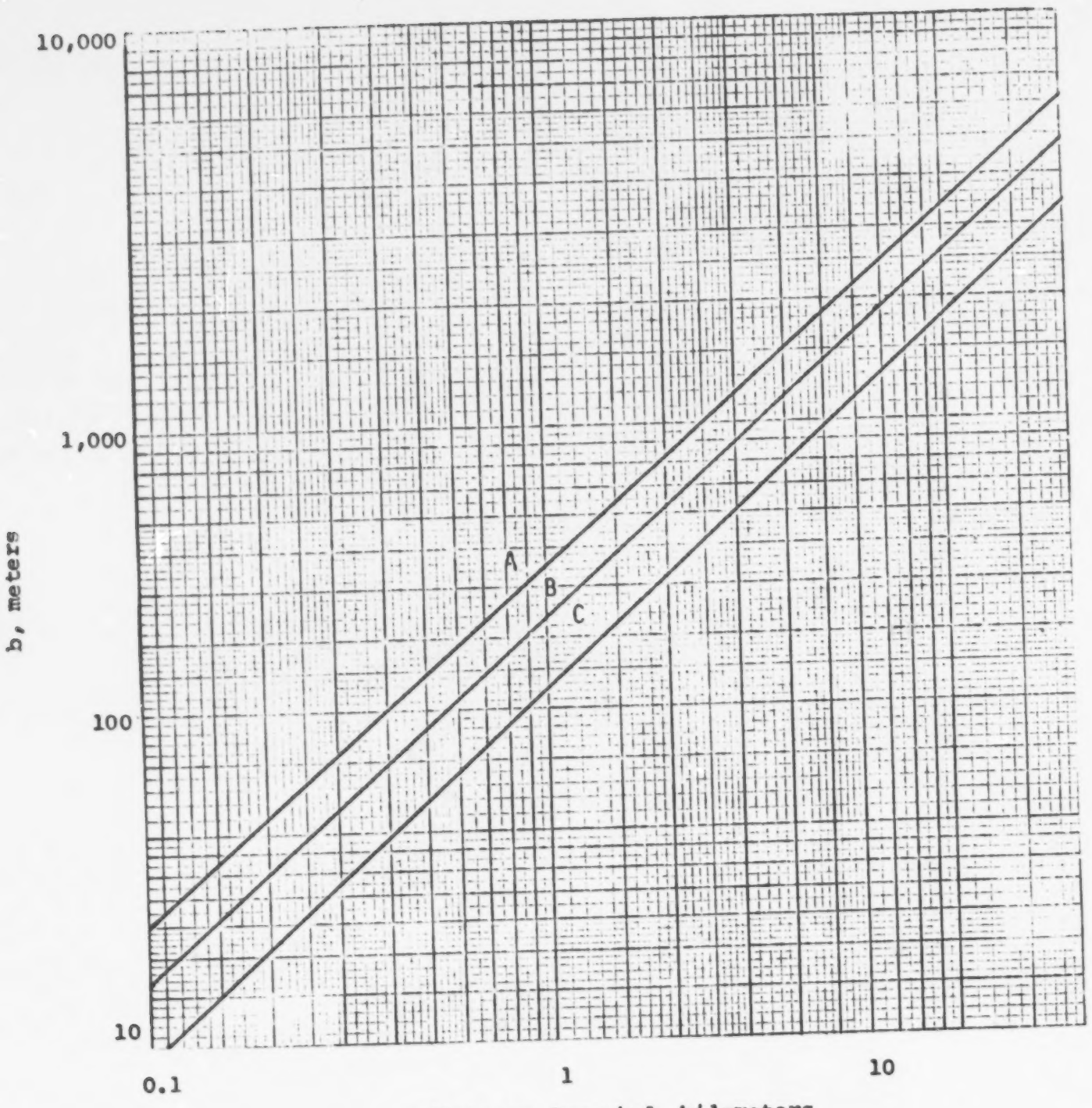
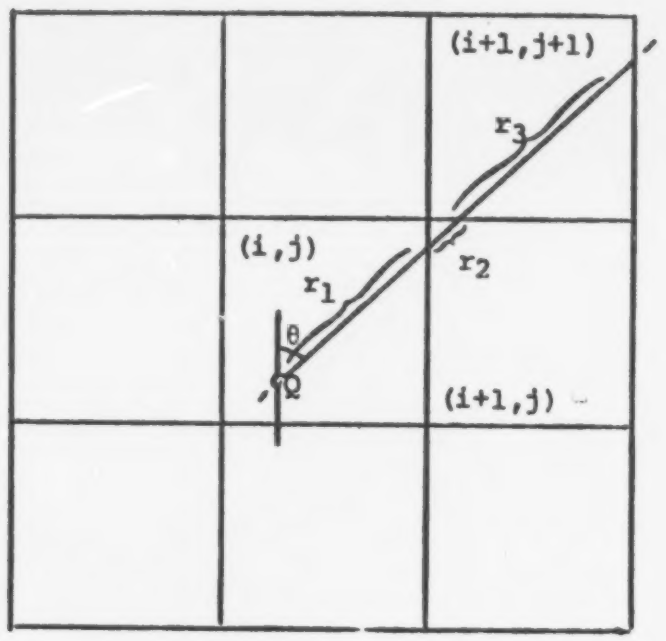


Figure A-10. Plume Half-Width as a Function of Downwind Distance From the Source



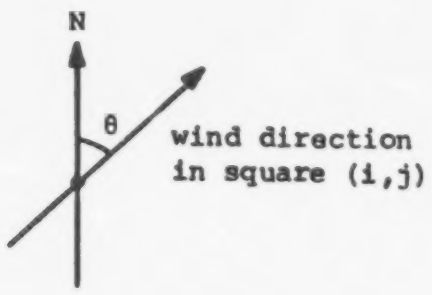


Figure A-11. Distribution of Point Source Emissions as Volume Sources in Adjacent Cells

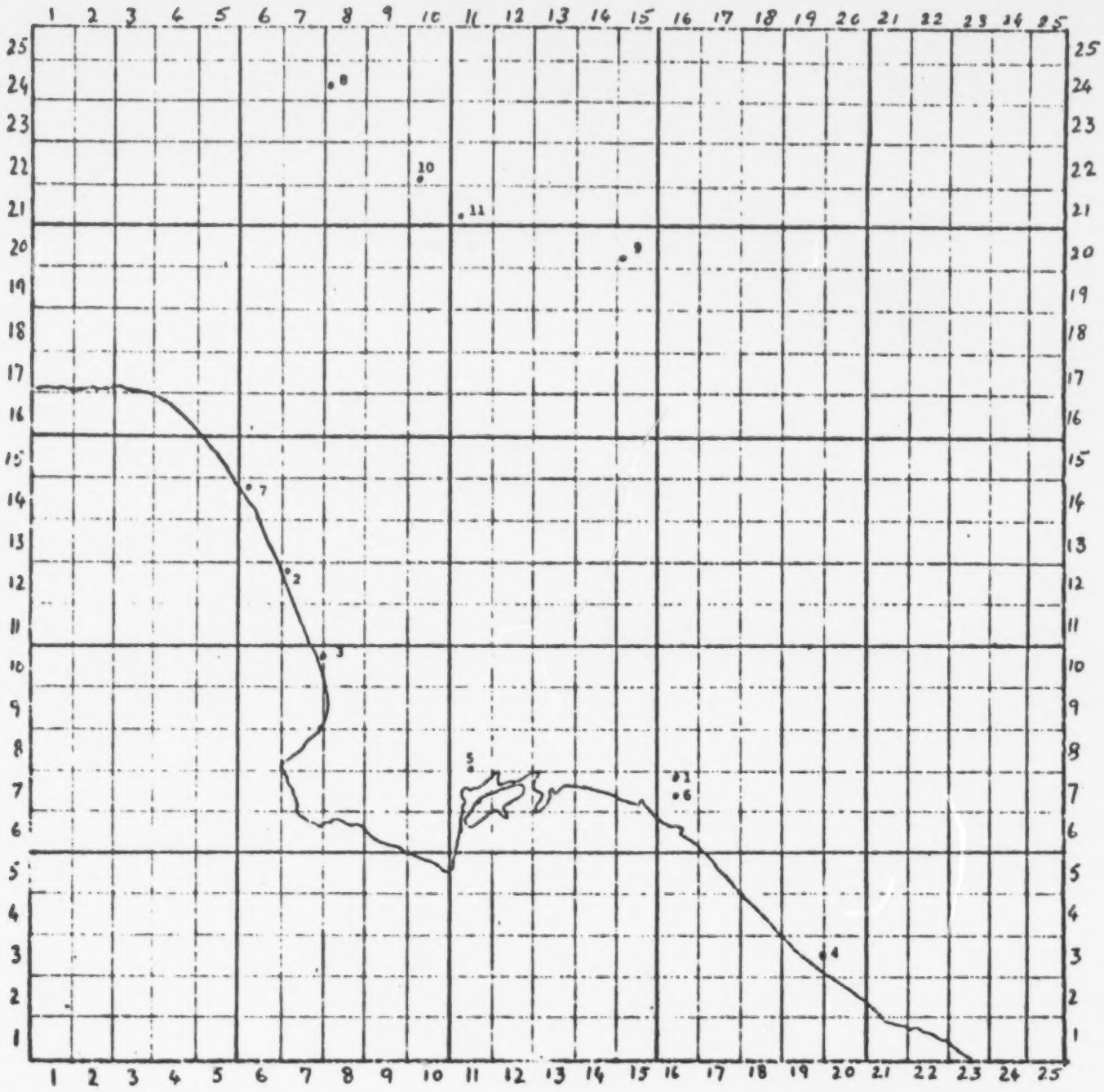


Figure A-12. Power Plant Locations

(See Table A-21 for numerical coding.)

Table A-20. Key to Stability Categories (Turner (1969))

Surface Wind Speed (at 10 meters), meters/second	Day Incoming Solar Radiation			Night	
	Strong	Moderate	Slight	Thinly Overcast or ≥4/8 Low Cloud	≤3/8 Cloud
< 2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	D	D	D

The neutral class, D, should be assumed for overcast conditions during day or night.

"Strong" incoming solar radiation corresponds to a solar altitude greater than 60° with clear skies; "slight" insolation corresponds to a solar altitude from 15° to 35° with clear skies. Table 170, Solar Altitude and Azimuth, in the Smithsonian Meteorological Tables (List, 1951) can be used in determining the solar altitude. Cloudiness will decrease incoming solar radiation and should be considered along with solar altitude in determining solar radiation. Incoming radiation that would be strong with clear skies can be expected to be reduced to moderate with broken (5/8 to 7/8 cloud cover) middle clouds and to slight with broken low clouds. An objective system of classifying stability from hourly meteorological observations based on the above methods has been suggested (Turner, 1961).

Table A-21. Locations and Capacities of Los Angeles Basin Power Plants

Plant Number**	Name	Plant Location (Square Number**)	Coordinates* of Plant Location (miles)	Electric Capacity (Megawatts)
Southern California Edison				
1	Los Alamitos	16,7***	0.8, 1.9	1950
2	El Segundo	7,12	0.2, 1.7	1020
3	Redondo Beach	8,10	0.0, 1.5	1530
4	Huntington Beach (Orange County)	19,3	1.8, 1.4	880
Los Angeles Department of Water & Power				
5	Harbor	11,8	1.4, 0.0	355
6	Haynes	16,7	1.1, 1.4	1580
7	Scattergood	6,14	0.9, 1.3	312
8	Valley	8,24	0.1, 0.7	512
City of Pasadena				
9	Broadway & Glenarm†	15,20	0.1, 0.5	230
City of Burbank				
10	Magnolia & Olive†	10,22	0.6, 0.1	174
City of Glendale				
11	San Fernando & Highland†	11,21	0.7, 0.5	153

*Horizontal and vertical distances, respectively, measured from the lower left-hand corner of the square containing the plant.

**See Figure A-12 for plant locations.

***Horizontal and vertical coordinates, respectively, with the origin at the southwest corner of the 50x50 mile area under consideration. (See Figure A-12.)

†Location, rather than name.

Table A-22. Power Plant Data

Plant Number[6]	Unit Number	Stack Height (feet)	Stack Diameter (feet)	Flue Gas Out of Stack: Mass Flow (10^3 pounds/hour)	Flue Gas Out of Stack: Volume Flow[1] (10^3 cubic feet/minute)	Flue Gas Out of Stack: Stack Temperature (°F)	Flue Gas Out of Stack: Velocity (feet/second)	NO_x Emissions (ppm)	NO_x Emissions (pounds/hour)
1	1	217	12.0	-	-	200	75	-	500
	2	217	12.0	-	-	200	75	-	500
	3	214	14.0	-	-	250	85	-	600
	4	214	14.0	-	-	250	85	-	600
	5	214	17.0	-	-	200	85	-	1200
	6	214	17.0	-	-	200	85	-	1200
2	1	222	12.0	-	-	210	75	-	800
	2	222	12.0	-	-	210	75	-	800
	3	220	14.0	-	-	205	80	-	600
3	11	219	14.0	-	-	90	30	-	20
	5	219	12.0	-	-	200	70	-	750
	6	219	12.0	-	-	200	70	-	750
	7	214	17.0	-	-	210	90	-	1450
	8	214	17.0	-	-	210	90	-	1450
4	1&2	211	17.2	-	-	230	40	-	900
	3&4	211	17.2	-	-	185	88	-	1800
5	1&2	250	8.7	705	243	338	78	384[2]	294
	3,4&5	250	9.7	1060	365	339	89	384	441
6	1&2	240	13.1	1880	585	260	75	160	328
	3&4	240	10.5[3]	1960	306	263	62	180	194
	5&6	240	18.5	2720	850	268	55	280	821
7	1&2	300	240.0[4]	1640	543	308	60[5]	96	171
8	1&2	250	12.5	1033	362	350	52	128	144
	3&4	250	15.0	1590	532	314	52	152	265

Table A-22 (continued)

Plant Number[6]	Unit Number	Stack Height (feet)	Stack Diameter (feet)	Flue Gas Out of Stack: Mass Flow (10^3 pounds/hour)	Flue Gas Out of Stack: Volume Flow[1] (10^3 cubic feet/minute)	Flue Gas Out of Stack: Stack Temperature (°F)	Flue Gas Out of Stack: Velocity (feet/second)	NO_x Emissions (ppm)	NO_x Emissions (pounds/hour)
9	1&2	60	11.4	375	-	220	-	180	34
	3	60	11.4	375	-	220	-	180	34
10		60	9.5	-	600	250	88	400	465
11	1&2	48	5.3	-	10	300	50	-	~6
	3	68	5.3	90	-	280	60	-	~20
	4	88	8.0	300	-	321	-	220	70
	5	88	8.0	488	-	190	-	130	37

[1]At stack exit temperature.

[2]Volume concentration at 20% excess air and wet for plants operated by the LADWP (plants 5, 6, 7 and 8)

[3]Two stacks per unit. Each stack has a diameter of 126 inches.

[4]One stack for both units.

[5]Exit gas velocity with both units operating.

[6]See Figure A-12 and Table A-21 for plant identification and location.

- Southern California Edison--Figures shown are interpolated from emissions tests made at an unspecified date, using power output records for 30 September 1969.

- Los Angeles Department of Water and Power--The figures shown are obtained from emissions measurements made at an unspecified date. NO_x mass flow rates are calculated from volumetric flow rate data.

- City of Pasadena--Data are based on emissions tests on one stack, and are inferred from these tests for the other stacks.

- City of Burbank--No data are available; figures are estimated.

- City of Glendale--Data are based on emissions tests made at an unspecified time.

B. Oil Refinery Model

Pollutants emitted by oil refineries are released from an array of stacks which are usually distributed over a large area and are of varying height. For this reason, and because individual refinery emissions data are not available to us, refinery emissions are treated as area sources, assumed to be well-mixed in the cell into which they are injected. Refineries are considered separately here because of the possible future need to deal with them in a different manner. We first describe the method whereby the emissions from each plant were estimated and then present the relevant data.

1. Distribution of emissions

As was mentioned, data relating to emissions from each individual refinery are not available. It was therefore necessary to make certain assumptions to arrive at usable figures. The total daily refinery emissions in Los Angeles County, as reported by the Los Angeles County Air Pollution Control District (see Section V), are:

Nitrogen Oxides	65 tons
Low Reactivity Organic Gases	49 tons
High Reactivity Organic Gases	5 tons

These emissions are distributed uniformly over 24 hours and in proportion to the crude capacity of each refinery. (See Table A-23.)

2. Emissions and relevant data

There are fifteen oil refineries located in the Los Angeles Basin. Data relating to oil refinery locations and their crude capacities are given in Table A-23. The number and location of each refinery are shown in Figure A-13. The emissions of nitrogen oxides and high and low reactivity organic gases are shown in Figures A-14, A-15, and A-16.

Figures A-13 to A-16 and Table A-23 follow

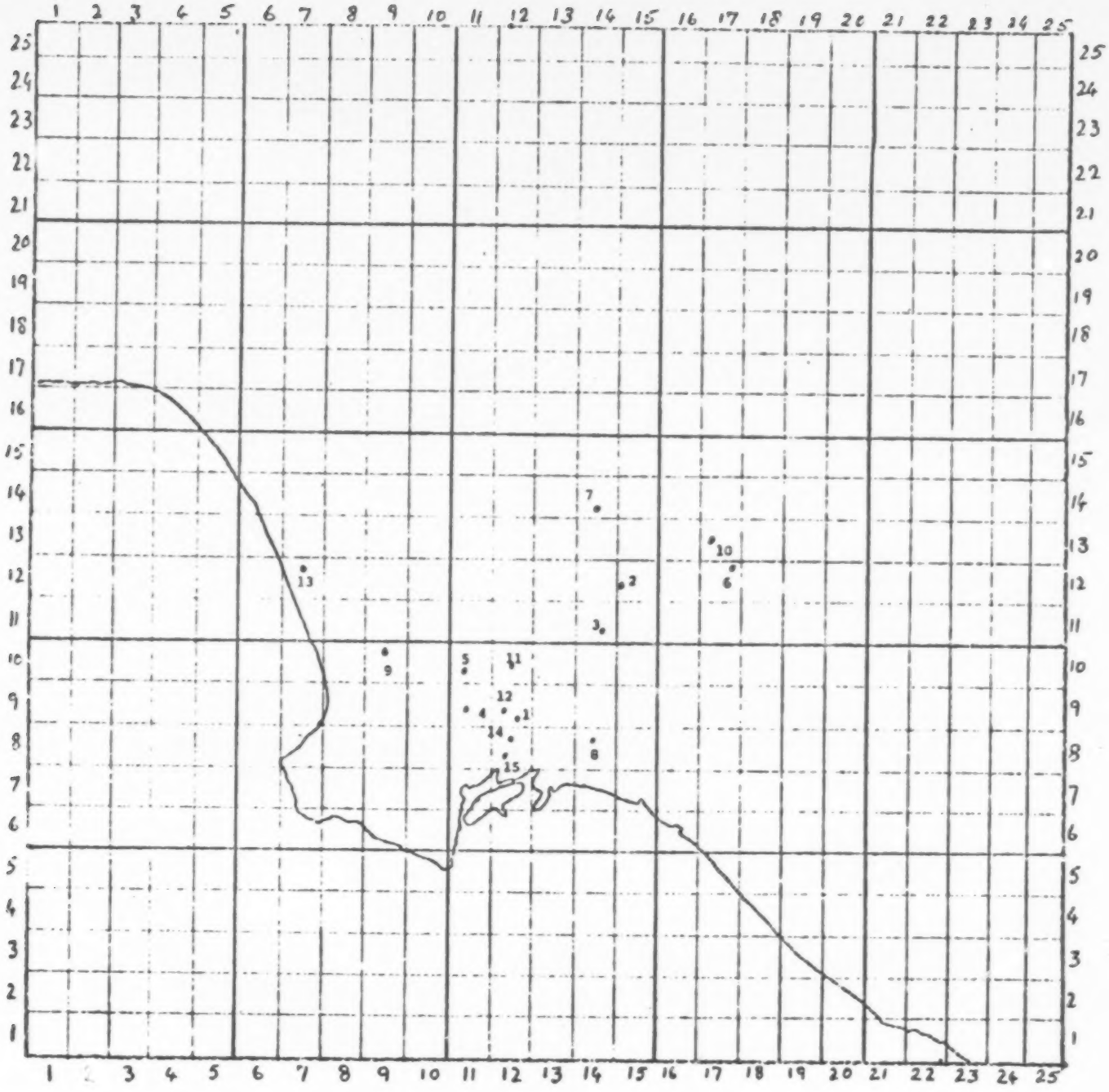


Figure A-13. Oil Refinery Locations

(See Table A-23 for numerical coding.)

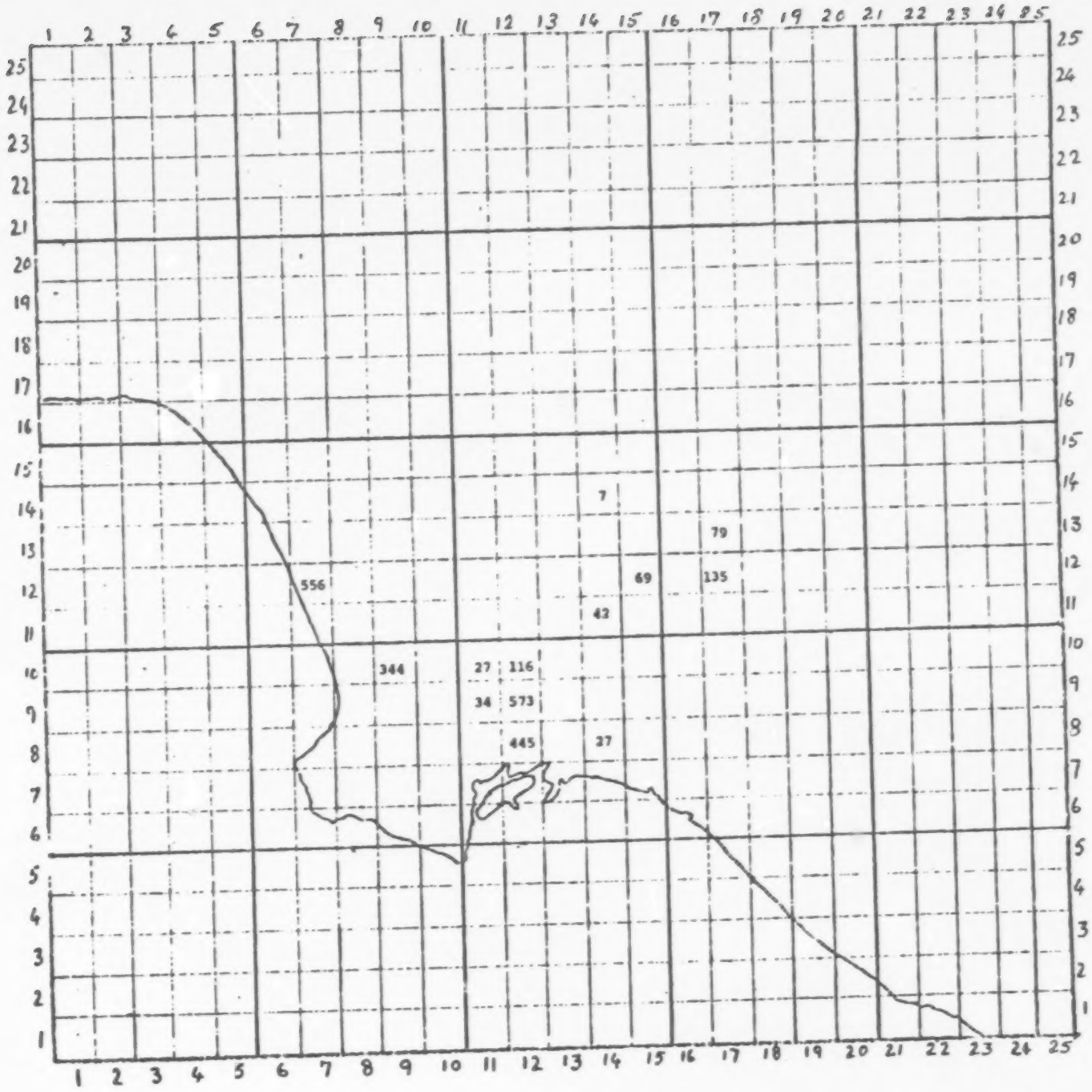


Figure A-14. NO_x Emissions (kilograms/hour) From Oil Refineries

Based on these assumptions, NO_x emissions between 6 a.m. and 6 p.m. PST over the highly populated areas of Los Angeles County are:

$$\frac{28 \times 2000 \times 454}{12 \times 262} \times 10^{-3} = 81 \text{ kilograms/hour/square}$$

Incineration contributes 1 ton/day. To operate incinerating equipment it is necessary to obtain a permit from the Los Angeles County Air Pollution Control District. Thus far there have been 1283 permit units issued for this purpose in the County.

Assumptions made in apportioning NO_x emissions due to incineration are:

(1) The total daily emissions occur between 6 a.m. and 6 p.m., PST;

(2) Emission rates are constant; and

(3) Emissions assignable to a grid square are proportional to the number of permit units issued for the five-mile square area containing that grid square.

The distribution of permit units is shown on page 17, "LACAPCD."

Mineral processing plants contribute 6 tons/day, mainly from concrete batch plants. These emissions are apportioned in the same manner as incineration emissions. The distribution of concrete batch plant permit units is shown on page 19, "LACAPCD."

Metallurgical plants contribute 3 tons/day. These emissions are apportioned in the same manner as incineration emissions. The distribution of metal melting equipment permit units is shown on page 18, "LACAPCD."

Petroleum Production contributes 10 tons/day. These emissions are apportioned in the same manner as incineration emissions, but spread uniformly over 24 hours. The distribution of petroleum processing equipment permit units is shown on page 20, "LACAPCD."

"Other Industries" contribute 25 tons/day, which are distributed uniformly between 6 a.m. and 6 p.m., PST, mainly over the southern central portions of Los Angeles County, with smaller amounts in the San Fernando and San Gabriel Valleys.

The total hourly NO_x emissions from all the above sources are shown in Figure A-19.**

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*Domestic, commercial and industrial facilities on firm natural gas schedules.

**The emissions rates shown in Figures A-19, A-20, and A-21 were computed for the hours 6 a.m. to 6 p.m. PST, and are assumed to be uniform over this time interval. Other rates would apply for hours outside this range.

Figure A-19 follows

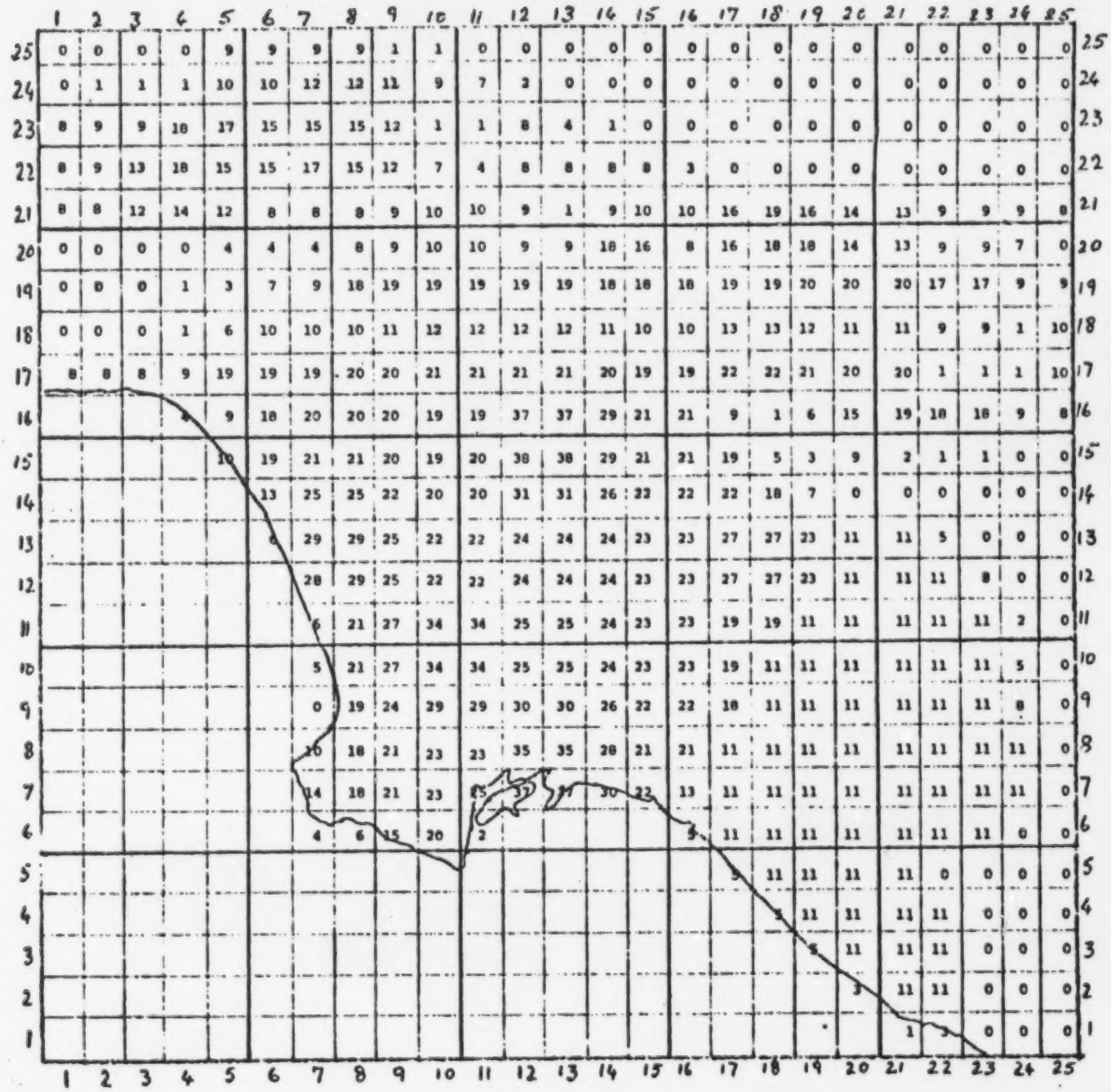

Figure A-19. NO_x Emissions (kilograms/hour) From Petroleum Marketing, Domestic, Ships and Railroads, Incinerators, Minerals, Metals, Petroleum Production, and "Other Industries"

2. Orange County

As the spatial distribution of industrial plants in Orange County is unknown, the following assumptions were made in distributing nitrogen oxide emissions from fixed sources:

(1) Half of the total daily domestic emissions (3 tons) occur between 6 a.m. and 6 p.m. PST.

(2) The total daily emissions due to mineral processing equipment, incineration, "other industries," and ships and railroads, a total of 6.5 tons, occur between 6 a.m. and 6 p.m. PST.

(3) Emissions from all sources listed under (1) and (2) are released in the 68 highly populated squares of Orange County.

(4) Emissions rates are constant.

Hence, NO_x emissions rates over the highly populated areas of Orange County, between 6 a.m. and 6 p.m. PST, are:

$$\frac{9.5 \times 2000 \times 454}{12 \times 68} \times 10^{-3} = 10.6 \text{ kilograms/hour/square}$$

These emissions are included in Figure A-19.

B. Organic Gases

1. Los Angeles County

Petroleum marketing, dry cleaning, degreasing and "other" organic solvent users contribute 105 tons/day of high reactivity and 275 tons/day of low reactivity organic gases.* These sources are assumed to be uniformly distributed over the 262 highly populated squares between the hours of 6 a.m. and 6 p.m. PST; thus,

$$\frac{105 \times 2000 \times 454}{262 \times 12 \times 10^3} = 30 \text{ kilograms/hour/square high reactivity organic gases}$$

and

$$\frac{275 \times 2000 \times 454}{262 \times 12 \times 10^3} = 79 \text{ kilograms/hour/square low reactivity organic gases.}$$

Surface painting and coating operations contribute 45 tons/day of high reactivity and 185 tons/day of low reactivity organic gases,

*The division of organic gas emissions into high and low reactivity was made by the Los Angeles County APCD, using a reaction scale similar to that shown in Table A-10.

mainly from paint bake ovens. These emissions are distributed uniformly between 6 a.m. and 6 p.m. PST in proportion to the number of paint bake oven permits in each square, as shown on page 16 "LACAPCD."

Petroleum production contributes 60 tons/day of low reactivity organic gases. These emissions are spread uniformly over 24 hours and in proportion to the number of petroleum processing equipment permit units in each square, as shown on page 20 of "LACAPCD."

Incineration, mineral processing plants, power plants, and "other industries" contribute 1, 1, 4 and 1 tons/day respectively. As these amounts are small, they were not considered here.

The total hourly emissions of organic gases from all the above sources are shown in Figures A-20 and A-21.

2. Orange County

Petroleum marketing, organic solvent users, and "other industries" contribute 9.7 tons/day of high reactivity and 39.1 tons/day of low reactivity organic gases. These emissions are distributed uniformly between 6 a.m. and 6 p.m. PST over the 68 highly populated squares; thus,

$$\frac{9.7 \times 2000 \times 454}{12 \times 68} \times 10^{-3} = 11 \text{ kilograms/hour/square high reactivity organic gases}$$

and

$$\frac{39.1 \times 2000 \times 454}{12 \times 68} \times 10^{-3} = 44 \text{ kilograms/hour/square low reactivity organic gases}$$

These emissions are included in Figures A-20 and A-21.

C. Carbon Monoxide

The total fixed source emissions of CO comprise approximately 0.5% of all CO emissions in the modeling area and thus were considered negligible.

Figures A-20 and A-21 follow

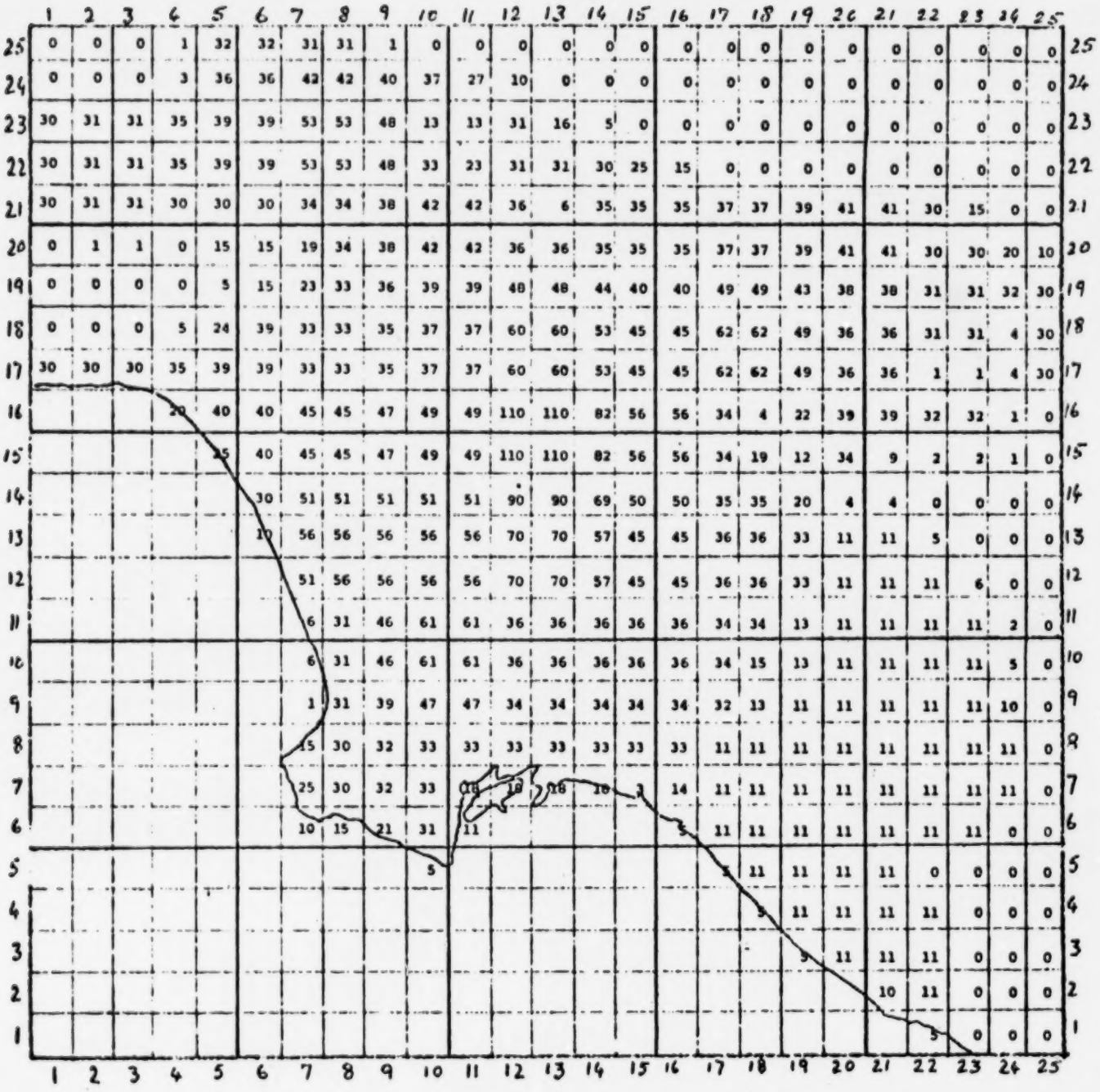

Figure A-20. High Reactivity Organic Gas Emissions (kilograms/hour) From Petroleum Marketing and Organic Solvent Users

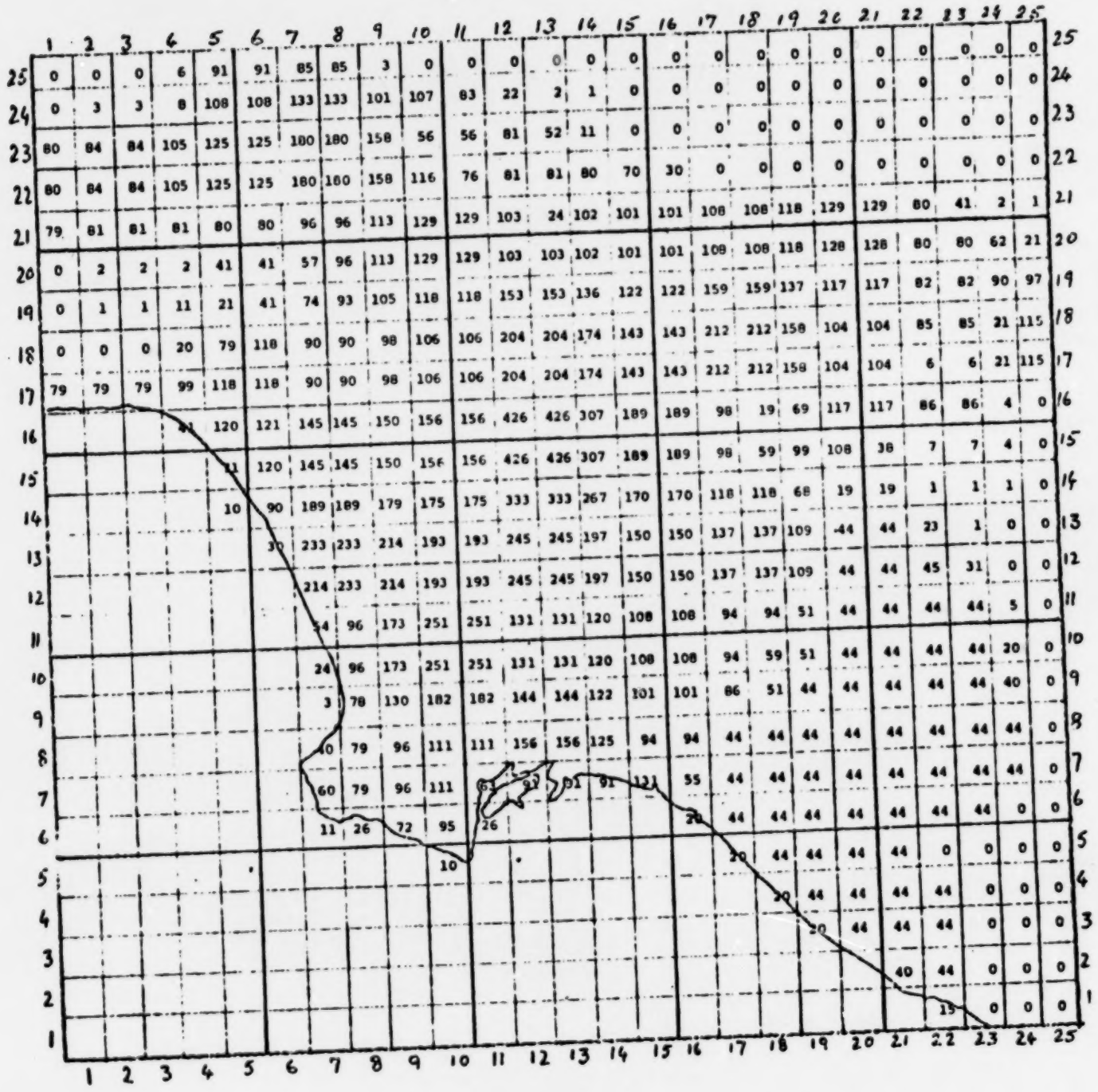

Figure A-21. Low Reactivity Organic Gas Emissions (kilograms/hour) From Petroleum Marketing, Organic Solvent Users, Petroleum Production

V. CONTAMINANT EMISSIONS INVENTORY OF THE LOS ANGELES BASIN

The purpose of this Section is to show the approximate magnitudes and relative contributions of the different emissions sources in the Los Angeles Basin. Average daily emissions rates of NO_x, organic gases and CO into the atmosphere of the Los Angeles Basin are shown in Tables A-25 to A-30. These data, with the exception of automotive emissions, were obtained from the appropriate County Air Pollution Control District.* Automotive emissions were computed from the product of the vehicle mileage in the parts of each county within the modeling area and the average emissions rate per vehicle (see Section I).

*The power plant data shown are total figures obtained from the counties and were not used in the model. They are included only for comparison. The power plant data used in the model and reported in Section IV are much more detailed.

Tables A-25 to A-30 follow

Table A-25. Emissions of Nitrogen Oxides in Los Angeles County[1]

Emission Source	Quantity (tons/day)	% of Total
Motor Vehicles[2]	466	60.4
Aircraft	15	1.9
Petroleum		
Refining	25	3.2
Production	10	1.3
Marketing	10	1.3
Power Plants	135	17.5
Oil Refineries	40	5.2
Other Industries	25	3.2
Domestic[3]	35	4.5
Incineration	1	0.1
Ships and Railroads	1	0.1
Metals	3	0.4
Minerals	6	0.8
	772	99.9

[1]Fixed source and aircraft emissions taken from: "Profile of Air Pollution Control in Los Angeles County," Los Angeles County Air Pollution Control District, January 1969.

[2]Computed from the product of our estimated figure of 4.4 grams of NO_x per vehicle mile and 96,358,000 vehicle miles per day, this being the vehicle mileage driven per day in Los Angeles County within the modeling area.

[3]Domestic, commercial and industrial facilities on firm natural gas schedules.

Table A-26. Emissions of Nitrogen Oxides in Orange County[1]

Emission Source	Quantity (tons/day)	% of Total
Motor Vehicles[2]	88.0	74.1
Aircraft	3.9	3.3
Minerals	0.3	0.3
Incineration	0.2	0.2
Power Plant (S.C.E. at Huntington Beach)	14.3	12.1
Other Industries	4.0	3.4
Domestic[3]	6.0	5.1
Ships and Railroads	2.0	1.7
	118.7	100.2

[1]Fixed source and aircraft emissions taken from: "Emissions Inventory--1969," County of Orange Air Pollution Control District, August 1970.

[2]Computed from: 4.4 grams/vehicle mile x 18,101,000 vehicle miles per day, this being the vehicle mileage driven per day in Orange County within the modeling area.

[3]Domestic, commercial and industrial facilities on firm natural gas schedules.

Table A-27. Emissions of Organic Gases in Los Angeles County[1]

Emission Source	High Reactivity Gases (tons/day)	Low Reactivity Gases (tons/day)
Motor Vehicles[2]	1037	183
Aircraft	45	45
Petroleum		
Refining	5	45
Marketing	50	60
Production	0	60
Organic Solvent Users		
Surface coating	45	185
Dry cleaning	5	20
Degreasing	20	75
Other	30	120
Incineration	0	1
Minerals	0	1
Power Plants	0	4
Oil Refineries	0	4
Other Industries	0	1
	1237	804

[1]See Ref. 1, cited in Table A-25.

[2]Computed from the product of our estimated figure of 9.0 grams of hydrocarbon/vehicle mile and 96,358,000 vehicle miles per day; plus evaporation losses equal to 72 grams/vehicle/day x 3,338,000 vehicles. As before, an 85:15 split between reactive and unreactive species is assumed.

Table A-28. Emissions of Organic Gases in Orange County[1]

Emission Source	High Reactivity Gases (tons/day)	Low Reactivity Gases (tons/day)
Motor Vehicles[2]	206.6	36.5
Aircraft	3.6	3.7
Petroleum Marketing	5.0	7.0
Organic Solvent Users		
Surface coating	2.0	8.0
Dry cleaning	0	2.5
Degreasing	2.3	0.4
Other	0.3	20.0
Other Industries	0.1	1.2
	219.9	79.3

[1] See Ref. 1, cited in Table A-26.

[2] Computed from: 9.0 grams/vehicle mile x 18,101,000 vehicle miles per day, evaporation losses equal to 72 grams/vehicle/day x 797,000 vehicles, and an 85:15 split between reactive and unreactive hydrocarbon species.

Table A-29. Carbon Monoxide Emissions in Los Angeles County[1]

Emission Source	Quantity (tons/day)	% of Total
Motor Vehicles[2]	6781	96.8
Petroleum Refining	30	0.4
Incineration	1	0.0
Metals	3	0.0
Aircraft	190	2.7
Oil Refineries	1	0.0
	7006	99.9

[1] See Ref. 1, cited in Table A-25.

[2] Computed from the product of our estimated figure of 63.9 grams of CO/vehicle mile and 96,358,000 vehicle miles per day.

Table A-30. Carbon Monoxide Emissions in Orange County[1]

Emission Source	Quantity (tons/day)	% of Total
Motor Vehicles[2]	1274	97.4
Incineration	0	0.0
Aircraft	30	2.3
Ships and Railroads	4	0.3
	1308	100.0

[1]See Ref. 1, cited in Table A-26.

[2]Computed from: 63.9 grams/vehicle mile x 18,101,000 vehicle miles per day.